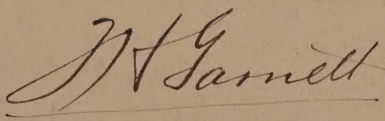

THE FLOTATION PROCESS

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THE BUTTE & SUPERIOR WORKS, AT BUTTE, MONT., WHERE THE FIRST GREAT FLOTATION PLANT IN AMERICA WAS INSTALLED.

THE
FLOTATION PROCESS

BY

HERBERT A. MEGRAW

Mining and Metallurgical Engineer. Member of the American Institute of Mining Engineers. Member of the Editorial Staff of the "Engineering and Mining Journal." Author of "Practical Data for the Cyanide Plant" and "Details of Cyanide Practice"

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PREFACE

The state of the art of concentrating ores by flotation is not such that a text-book can be said to cover the field with any degree of intensiveness. The process has not been sufficiently developed to provide a basis for a work that will endure for a great length of time without careful, perhaps radical, revision. The theory upon which the process operates has not been fully elucidated, and practice certainly has not been so formulated that much forecasting can be indulged in. The probabilities are that flotation is still in its swaddling clothes and the measure of its full growth cannot be even imagined now. That its usefulness will continue to increase for a long time seems unquestionable.

To assist in the development of such an important step in metallurgy is worth any effort that may be made, and it seems that accumulation of the results of practical and theoretical investigations that have been carried out by many men at many places is an important aid to further development. My part in the furtherance of flotation is this compilation, which presents the information about the process that I have been able to acquire by practice and consultation. To simplify as much as possible has been a primary object and I have endeavored to eliminate most of the speculation that has encumbered the literature of the process up to this time, retaining only those parts that have been definitely proved correct, or can show a reasonable basis for their inclusion.

No one can claim, at this time, to know enough about flotation to pose as a master of the art. Any attempt to be complete must include the work of many individuals and the ideas of many more. I make no claim of originality for the facts put forth in this book. They have been gathered where they could be found and have been used as has seemed most appropriate. The original volume of Theodore J. Hoover has been referred to often,

and credit has been given. I owe much to that work and believe it will always remain a classic in flotation.

The reason for this book is simply that great changes have been wrought in practice and also in the theory, so that some further words seem advisable. The technical press has been freely used as a source of information, consequently much of the material has already appeared in print. There is some virtue, however, in concentrating facts so that, as with ores, one need not be burdened with material foreign to the subject.

It is impossible to thank individually the long list of operators and experimenters who have supplied material for the book. Many of them are named and references are made to their work, but much of the information has been supplied with the request that no names be mentioned as to its source. By this acknowledgment these gentlemen may know that my thanks go to them as well as to those who are specifically named.

No apologies are made for the many sources of the information that is given. To be of service, no other method is possible. If it aids operators in the advancement of a worthy metallurgical development its object will have been accomplished.

HERBERT A. MEGRAW.

New York,
August 18, 1916.

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THE FLOTATION PROCESS

CHAPTER I

CONCENTRATION BY FLOTATION

The word "concentration," when applied to the metallurgy of ore, is understood to mean any process through which the valuable constituent of the ore is segregated into a portion of less weight than the original total mass. The degree of concentration may be anything from the point where only a small amount of valueless material is taken out to the point where all the waste material is removed and nothing but the valuable material left. Exemplifying various degrees of concentration are the processes of, first, ore sorting, which is a form of manual labor, by means of which a part of the ore that may be recognized as valueless is picked out and thrown away. Ore grades may be raised much or little by this process, but as a practical system of metallurgy it is falling into disuse, although largely practiced in former times.

A second process of concentration is that by means of which an ore is fluxed and smelted, the concentrate containing all of the valuable metal, whether it be gold, silver, copper, lead, or whatever metal is sought, and the discarded portion containing nothing of economic worth. As a matter of fact, practically all processes of metallurgy are, in effect, concentration.

In modern metallurgy, however, we do not take such a wide interpretation of concentration. The word is usually understood to refer to those processes by means of which mechanical aid is employed to separate, as completely as possible, the siliceous gangue from a high-grade, metal-bearing mineral. Such processes almost invariably require the use of grinding machinery to prepare the ore for its mechanical separation. Grinding is carried to such point as will permit the separation of the purely mineral portions from the purely gangue portions of the

ore, or if this is not wholly possible, then to approach that desideratum as closely as possible.

Concentration, as heretofore understood, referred to the separating of minerals and gangues by two classes of machinery: those that treat ores wet and those that treat them dry. In either case, the separation was accomplished by taking advantage of the difference in specific gravity of the mineral and the gangue. Minerals, carrying metals, have specific gravities that are usually higher than gangues, although there are exceptions to this statement. In the dry-concentrating machines, a controlled current of air is used to blow away the lighter gangue, allowing the heavier minerals to remain on a plane surface or to fall directly into appropriate receivers. In wet processes the higher specific gravity of the minerals is taken advantage of by allowing them to fall through a moving current of water, the lighter gangue material being carried away by the current and washed clear of the mineral. This is by far the most widely applied system of concentration, and a great number of machines have been devised to make use of its principles. Jigs, vanners, buddles, concentrating tables, canvas tables, blankets, riffles, cement tables, and many other devices have been used for the purpose. All of these machines are well known to the metallurgist, and it would be futile to attempt to review them here.

Coming to the new process, it seems peculiar that while for all these years we have taken advantage of gravity to aid us in separating mineral from gangue, now we have embraced a process that uses gravity differently. In its place we are utilizing another well-known principle—that of surface tension. Although commercial application of the process has been accomplished only within the last few years, mill operators have, since the beginning of time, been annoyed and puzzled by the action of minerals and metals under some conditions. The amalgamator has always been bothered by his fine gold, or "greasy gold," or tabular gold, which persisted in floating away from his amalgamated plates, despite all his efforts to gather it. The principle that is responsible for the action of gold under these conditions is the principle we are now training and making use of in flotation processes. It is really, as W. R. Ingalls has so aptly put it, "concentration upside down."

Operators of concentration mills have always noticed the escape

of finely ground sulphides on the surface of water, and they have never been able to overcome that flotation tendency. In the concentration of molybdenite ore, the floating tendency of that mineral has sometimes made ordinary gravity concentration impossible. Even the cyanide-plant operator has often encountered a high-grade floating scum that he never could entirely abolish. The fact that it was usually rich led many operators to devise mechanical means for recovering it. Flotation, then, is merely the recognition of the existence of these tendencies, and the utilization of them in securing better results than could be obtained by gravity concentration.

The process is comparatively new. The chemical and physical principles upon which it depends have not been investigated with sufficient thoroughness to allow the formulation of a definite theory, but great steps have been made and we have enough to base practical work upon. It is found, however, that metallurgists must widen their reading if they desire to keep abreast of flotation. Principles of physics must be freshened up, and something must be known about colloid chemistry. Flotation concentration is not an empirical procedure from which success may be obtained by mere perseverance. Some education and skill is definitely required and some excursions into the realm of pure science if the operator is going to learn anything or be able to use his judgment in a profitable way.

Flotation concentration, then, is the taking advantage of the principles of surface tension and colloid chemistry, with whatever allied principles may be involved, to separate mineral from gangue by means of floating it upon the surface of water or other solutions, while the gangue is induced to sink through the surface and settle separately.

CHAPTER II

THE PATENT RECORD OF FLOTATION

The art of flotation is one of the newest efforts in metallurgical endeavor, and one that is entitled to great respect by reason of the enormous and widespread success it has attained within a comparatively short time. While no one knows just where the process, as at present understood, originated, it is possible to trace back the most important steps through the records of the patent office. Naturally, a great many important ideas never reach the patent office, but develop gradually until they appear before the public as highly perfected systems, but for one process developed in such a quiet way there are very many whose infantile efforts are recorded in the patent-office files and, it may be truly said, many of them never get any farther. A great deal of interesting information may be obtained from patent data, and a brief survey of the record, so far as it is possible to follow it, will be interesting and instructive to the student of the art.

The Patent Record of Flotation.—The first one of these that is widely known is the patent obtained by William Haynes, in 1860, upon a process for separating mineral sulphides from gangue by oil, gummy, or bituminous matter. This patent is upon a process that is not flotation, since it attempted to remove sulphides by having them adhere to a viscous oil. It is, however, worthy of record as one of the first steps in flotation, since it recognizes the tendency for sulphides to adhere or mix with oils to a much greater extent than gangue particles or oxides.

The next patent in line is that of Hezekiah Bradford, granted in 1886. Bradford's is a process based upon surface-tension factors. The flotation of sulphides on liquids is pointed out in detail, but there have been, so far as is known, no commercial applications made of the specifications as set forth in the patent. It is important, as are all such steps, since it points out a growing and widening recognition of the features that are so well

known at the present time as affecting flotation. The trend of events is perfectly clear, in that there is a development from the first agglomerating systems, which recognize only the tendency of sulphides to adhere to oils and are dependent upon viscosity to separate them from the gangue, to the bulk-oil separation processes, by means of which the buoyant property of oil is taken advantage of to float the maximum amount of mineral that the oil will carry, graduating from that into surface-tension systems, through which minerals float due to surface forces, until we finally reached the stage where it was found that gas or air bubbles would attach themselves readily to oiled mineral sulphides and tend to float, whereas the gangue exhibits a contrary tendency. The use of acids was a step that proved of great importance, since it altered the character of the liquid medium.

The Advent of Mrs. Everson.—With the development of the acid process, we come to the next important patent of the series, known as the Everson patent, granted in 1885. There is probably no figure in metallurgical history about whom there has been so much belated interest as Mrs. Everson, nor is there any one, probably, about whom so many erratic statements have been made. It will be interesting to study briefly a true account of her work in flotation, a résumé of which has been already published.*

Carrie Jane Billings Everson was born at Sharon, Mass., in 1842. She was graduated from High and Normal School and, in 1864, was married to Dr. W. K. Everson, at Chicago. Dr. Everson was an old-school physician, druggist, and chemist. Mrs. Everson first took up the study of medicine with her husband as tutor and subsequently specialized in chemistry. She never attended medical or engineering schools. She was attracted to mineralogy through Dr. Everson's investments in mining enterprises in Colorado and Mexico. Her inclination was toward whatever scientific subjects came nearest to her daily life. She was interested in medicine because her husband was a physician, and her medical knowledge was considered equal to that of Dr. Everson. She was interested in chemistry as an allied science, and became a better chemist than her husband. Mineralogy attracted her because she believed that mining would become pecuniarily profitable as well as scientifically interesting.

* *Eng. and Min. Journal*, Jan. 15, 1916.

Mrs. Everson had a brother who was an assayer, but whose practice and research had nothing to do with mineralogy or mining, so that he gave no instructions whatever in her experiments, although it has so often been stated that Mrs. Everson's interest in flotation came about through an accidental discovery while assisting her brother in some mineralogical work. The assistance obtained from her husband was merely of a consulting nature. While he was naturally interested in mineralogy and metallurgy through his investments and his wife's research, he did not attempt the study of the subject nor bring his own mind to the practical treatment of ores.

Dr. Everson's mining investments brought him nothing but loss and practically total financial disaster. Mrs. Everson probably began her study of mineralogy as early as 1878, and about 1880 began the investigation and research that resulted in her patent in 1886, while her husband was in Mexico. The Eversons removed from Chicago to Abilene, Kan., and thence to Denver. Dr. Everson died in Denver in 1889. Mrs. Everson had given up hope of any return from their investments in mining, but she believed strongly in her invention and thought that if given proper attention the flotation process would be applied commercially and economically to the metallurgy of ores.

At the time of Dr. Everson's death, their son, John L., was about seventeen years old. Through association and tutelage the boy became practically interested in the process, and when, in 1890, Thomas F. Criley formed the partnership with Mrs. Everson, young Everson assisted him in a practical demonstration at West Cliff, in the neighborhood of Silverton, Custer County, Colo. These experiments and demonstrations were considered satisfactory in results, but so little encouragement was offered them in Colorado that it was determined to send Criley to Baker County, Ore. There was at that time, or had been just prior thereto, some mining excitement in the Sparta district, in the Powder River region. Criley put up a demonstrating plant and experimented successfully with sulphide ores of the district, and also made some demonstrations at Baker City. He died either at Baker City or Portland, and Mrs. Everson went to Oregon in the hope of straightening the tangle in which the affairs were left at the time of Mr. Criley's death. She was not a good promoter nor business women, and nothing of practical

benefit resulted from her efforts or those of Criley in Oregon.

According to her son, John L. Everson, after Criley's death, subsequent failure to interest mining companies or investors in the oil-froth method, his mother made but little effort to continue the exploitation of this process and devoted her time to research and experiment with a dry process of flotation. In conjunction with Chas. D. Hebron, a patent was taken out about 1892. Hebron secured the financial assistance of a Mr. Pischel, also of Denver. They obtained the use of a chemical laboratory and plant in a suburb of Denver and proceeded with the experiments and demonstrations of Mrs. Everson's dry process of flotation. Hebron and Pischel got into a quarrel over money matters or division of interest, and finally Mrs. Everson gave up hope of any financial benefit from either of her processes.

Mrs. Everson went to California in 1909 to make her home with her son at San Anselmo, where she died on Nov. 3, 1914. For two or three years just prior to going to California, she taught physiology and hygiene in the State Reformatory for Girls at Morrison, Colo. From this might have been obtained the impression that the inventor of flotation process was a school teacher. Mrs. Everson had never taught school at the time her flotation experiments were made, although she was graduated from a normal school and was prepared to take up teaching as a profession. Her marriage turned her mind and her talent toward medical and chemical science, and thence, naturally, in view of their mining investment, to mineralogy and metallurgy. That she did not receive any benefit from her discovery was due primarily and largely to the loss of her husband's accumulated earnings, but in no small degree to the fact that as a metallurgist she was a quarter of a century in advance of her profession.

The Everson Patent.—The original Everson patent granted in 1885 specified a process for separating sulphide in an ore from gangue. The selective action of oil for sulphides, discovered by Haynes, was utilized in her invention, but she discovered in addition that acid added in small quantity to the pulp greatly increased the selective action of the oil, and the oiled mineral could be separated from the gangue by giving the mass a thorough agitation and allowing the sulphide and oil to float to the surface. The amount of oil used is variously stated in her ex-

periments, varying from 6 to 20%, and the amount of acid was usually less than 1%. In considering the Everson patent, it must be carefully borne in mind that none of the amounts of oil specified by Mrs. Everson were enough to float sulphide purely by reason of the buoyant properties of the oil, but were only sufficient to provide a froth that would enable the sulphides to be carried to the surface and floated. It will be of interest to review here a copy of the original Everson patent.

CARRIE J. EVERSON, OF CHICAGO, ILLINOIS

Process of Concentrating Ores

Specifications forming part of Letters Patent No. 348,157, dated August 24, 1886.

Application filed August 29, 1885. Serial No. 175,665. (Specimens.)

To all whom it may concern:

Be it known that I, Carrie J. Everson, of Chicago, in the county of Cook and State of Illinois, have invented a certain new and useful improvement in Processes of Concentrating Ores; and I do hereby declare that the following is a full, clear, and exact description thereof.

The discovery which forms the basis of my invention is that metals and metallic substances in a comminuted state will unite with compounds of fats or oils and acids, and that such compounds will not unite with comminuted quartz or other rocky gangue. The essential feature of the method which constitutes my invention, therefore, consists in commingling with pulverized ore a fat or an oil, either animal, mineral, or vegetable, or a fatty constituent or acid of an animal or vegetable fat or oil, or any constituent of a mineral oil, together with an acid, either mineral or vegetable, or a soluble neutral or acid salt, for the purpose of effecting a union of the free metal or metallic portion of the ore with such admixed material, whereby the same may be retained in the subsequent separation of the quartz or other rock therefrom by washing or other suitable means.

The invention is more specially applicable to the treatment of ores in which the metal or metallic portion is mixed with quartz or other rock as distinguished from the mixture of mineral with clay, though it is applicable to ores containing alumina, together with quartz or other rock, to the extent of permitting the removal of the silica or sand.

The operation of concentration as a whole, or in its practical form as applied to the separation of rocky mineral ores, involves the reduction of the quartz or other rock containing the mineral to a powder, the

addition thereto of the fat or oil and acid or salt, and the subsequent removal of the gangue.

If my invention is inapplicable to any particular rocky ores or class or classes of rocky ores, or to the concentration of any particular metal, such limitations are not now known to me. Its commercial value, however, will probably be restricted to its use in connection with ores bearing the precious metals, such as gold, silver, and copper.

Among the ores upon which I have operated successfully by means of my invention are the following: Ores containing native gold and silver, kerargyrite, argentite, argentiferous galena, and a variety of double and otherwise compound sulphides of silver, with copper, antimony, arsenic, and other base-metal sulphides. I have also operated successfully upon pyritic ores, white, yellow, green, and intermediate shades, having variable constituents of iron, copper, arsenic, and sulphur, and mostly auriferous, and having variable proportions of such constituents. I have also operated successfully upon ores containing tellurides of gold, silver, and lead, and others containing the oxides and carbonates of copper and the carbonate of lead. All the metals or metallic mineral portions of these ores are acted upon by the admixture described, in such manner as to permit the rocky gangue to be removed by a washing process, after which several metals may be separated by the usual means.

In putting my invention into practice any fat or oil, and any acid, either mineral or vegetable, or any soluble neutral or acid salt, or any compound of fats and oils with appropriate acids, may probably be successfully employed, at least such is the case with all of these agents with which I have so far experimented. I have used petroleum and one of its several constituents—namely, paraffin oils—also tallow, (melted,) lard, lard-oil, red-oil, (impure oleic acid,) cottonseed oil, castor-oil, sperm-oil, and linseed-oil, and some combinations of these with each other. The acids which I have employed are sulphuric, hydrochloric, nitric, phosphoric, acetic, oxalic, tannic, and gallic. I have also used the following salts, to wit: the sulphates and chlorides of sodium, zinc, and copper, and the double sulphate of potash and alumina. The selection of the appropriate agents will, however, be largely determined in the practical working of my invention by the consideration of economy, which will obviously exclude the greater number of those above enumerated. A reasonably cheap and practicable use of my invention will be as follows, the quantity named being suitable for laboratory use and the character of the ore specified being substantially that of an ore upon which I have successfully operated by the preparation and in the manner hereinafter described.

Take an ore assaying twelve ounces per ton in silver and containing

forty-eight per cent. silica, 6.3 per cent. zinc, 1.5 per cent. copper, fifteen per cent. iron and aluminium, 6.5 per cent. lead, 14.18 per cent. sulphur, 7.19 per cent. arsenic. Of this ore take four (4) ounces by weight in pulverulent form, prepare a mixture containing sulphuric acid, cottonseed oil, and water, in all about twelve fluid drams of which ten drams are of water and about two drams are acid and oil in the proportions of fifteen parts of the oil and two parts of the acid by measure. In making this fluid mixture the acid and oil are first mixed with each other, the acid being added to the oil very gradually, so that the temperature will not rise above 120° Fahrenheit. The stirring in of the acid should be thorough, as it tends at first to gravitate to the bottom. After a few hours, in a summer temperature, the mixture will be ready for use, and, preferably, in such a temperature should not be prepared long before using; though if it should have stood long enough to solidify it should be gently heated before adding the water thereto. In winter or in air-tight vessels it may be kept for a number of weeks or even longer, and then rendered fit for mixing with water by heating gently when required for use. The water may be advantageously added in installments of about three equal parts, and the mixture stirred after each addition of water until it stiffens. After stirring in the entire quantity of water the compound is added to the ore, the proportions of ore and compound being chosen with a view to producing a stiff mass after the materials have been incorporated, such proportions being therefore variable in different cases with this end in view. The stirring or incorporation of the ore with the liquid should of course be thorough for the purpose of bringing the mineral into contact with the oil and acid as completely as possible, and after such incorporation the mass is then in condition for the washing out of the quartz by the action of water which will be applied to the mass in sufficient quantitites for this purpose. The washing should promptly follow the mixing, and in this operation the mass be opened out or broken up and thoroughly stirred in the water, in order that the sand or quartz may be freed and carried away. In treating so small a bulk as above specified the mass may be squeezed repeatedly in the hand in a basin of water, the substance so manipulated being expressed between the fingers each time it is squeezed, and thus made to expose new surfaces to the water from which the sand will be detached, so as to fall to the bottom of the basin. In practice upon large masses any vessel having an outlet or outlets at its bottom for the escape of the water and sand will be suitable for this operation of washing, and mechanical means will of course be employed to break up the mass. The concentrated mineral will accumulate in a pasty mass or lump or lumps and will contain the metallic portion of the ore, together with the hydrated oil and acid, which latter

may be removed by heating and afterward roasting, or by other suitable means. The use of petroleum or of a constituent thereof, either by itself or in combination with tallow, (heated,) cotton-seed oil, or other fat or oil, will be even less expensive.

When petroleum or a constituent thereof is used the oil should desirably be first mixed with the ore, then water added containing a suitable amount of free acid or a soluble neutral or acid salt, the quantity of water being ample for the washing-out operation, which is to follow, and the quantity of acid sufficient to cut the sand away from the otherwise cohering mass. In the case of petroleum or its constituent, paraffine-oil, one or two fluid drams of acid to one gallon of water is sufficient for this purpose. The petroleum which I have used was 30° Baumé, and I have found three fluid drams of oil abundant for properly moistening two ounces of heavy ore, or in the ratio of about a barrel of oil to the ton of ore, the amount being, of course, variable with the relative bulkiness of the ore.

In the use of petroleum, or of a liquid constituent thereof, like paraffine-oil, the condition of the concentrated mass is more liquid than when a vegetable or an animal oil or a fatty constituent thereof is used, and a somewhat different means or method should be employed for removing the sand. In practice, the concentrate, after thorough agitation of the mass and detachment of the sand, will in this case be preferably removed by means of a constant overflow of water from a washing-out vessel, by which overflow the concentrate will be floated off. Devices and methods now well known in wet separation of ores will be suited to this part of the operation, bearing in mind that the sand and mineral are merely transposed or their relative positions are reversed, because the sand is heavier than the mixture of mineral, oil, and acid. A proper selection of devices for this purpose will be apparent to those skilled in the wet separation of ores. After removing the quartz or rock by washing or any suitable means the mineral may be roasted, in which operation the water, if present, will be dispelled, the oil will burn out, and the acid will be decomposed and eliminated, in the case of sulphuric-acid, which will commonly be used, by conversion into sulphurous-acid gas, which passes off. In case fixed oils are used the mass may be allowed to stand until the water has run off. To hasten the operation of removing the water the mass may be heated, say, to about 212° Fahrenheit or less, whereupon the water will generally be promptly freed and may be poured off or it may be evaporated. The operation of smelting is facilitated by the presence of the fat acting simply as a fuel.

The disposition made of the mineral or metal after concentration, whether by roasting and subsequent smelting or by smelting without previous roasting, or otherwise, belongs to the after treatment and is

not material to my present invention. The proportions in which the acids or salts are added to the oils or fats may vary according to the kind of acid or oil employed, and also according to the kind of ore to be treated; and the manipulation of the substances employed may be varied from that above set forth in either formula given. These matters may be determined in individual cases by the operator; and I do not, therefore, restrict myself to any particular proportions of the substances employed, though I have above indicated proportions of certain acids and oils by one or the other of which practical results may be obtained upon almost all varieties of ores.

It is also not essential to my invention that the acid or salt employed with a vegetable oil be added to the oil before the incorporation of the oil with the ore, as it is entirely practicable, at least in most, and possibly in all, cases, to first mix such oil with the ore and thereafter add the acid, as set forth in the use of petroleum.

I am aware that it has been proposed in a patent to Tunbridge, No. 228,004, dated May 25, 1880, to recover finely comminuted metal held in suspension in water by the use of soap or a saponaceous compound formed by a partial or imperfect blending of an alkali or an alkaline salt with a fat or an oil. The action of the soap or saponaceous compound when diffused through hard water containing the metal in suspension is to form with the lime salt in the water a coagulum in which the particles of metal are enveloped and by which they are held during a subsequent removal of the water. When the water is soft a lime salt must be added to form the coagulum. I disclaim the use of any substance in connection with the fats and oils capable of saponifying them. I also disclaim the method set forth in said Tunbridge patent as being entirely dissimilar to that herein claimed. Said Tunbridge method is stated in said patent to consist "in first depriving the water of as much earthy non-metallic matter as possible," this being effected by any of the ordinary methods in use for that purpose, such as letting it stand until the earthy matter precipitates. My invention, on the other hand, has reference solely to the separation of metal or metallic mineral from earthy non-metallic matter, (rocky gangue,) and not to its subsequent separation from water. In the practice of my method, moreover, the metal or mineral and non-metallic matter (rocky gangue) are together and in the first instance mixed with the fat or oil, and the non-metallic matter is afterward separated from the metal or mineral by the peculiar action of the acid or soluble neutral or acid salt operating in the presence of water to detach the gangue from the mass.

With the understanding that I am not restricted in the matters mentioned, I claim, broadly—

1. In the separation of pulverulent ores containing rocky gangue,

the method of treatment herein described, which consists in mixing with such pulverulent ore a fat or an oil or a constituent thereof, an acid or soluble neutral or acid salt, and water, finally breaking up the mass to allow the sand to separate therefrom.

2. The method, substantially as described, of separating metals or metallic minerals from rocky gangues, which consists in mixing a fat or an oil or a constituent thereof with pulverized ore and washing out the gangue with water containing an acid or a soluble neutral or acid salt.

In testimony that I claim the foregoing as my invention I affix my signature in presence of two witnesses.

CARRIE J. EVERSON.

Witnesses:
M. E. Dayton,
G. F. Lanaghen.

The original Everson process was improved in 1892 by the patent of Hebron & Everson, in which pulverized ore was mixed with a buoy-stock in a dry state and then the prepared ore was applied to a stratifying apparatus into which air could be introduced for the purpose of producing a froth.

Robson & Crowder Process.—During the life of these processes, and for some time afterward, little was heard of flotation and practically no economical advantage was taken of the principles involved. In 1894 Robson & Crowder brought out a process for separating the gangue and sulphides, but they made use of oil selection only. Their invention was very little, if any, different from the ones that had gone before. In 1898, F. E. Elmore invented the bulk-oil process which has always borne his name. In this process the total ore pulp was mixed, in water solution, with a large bulk of oil. The oil was used in sufficient quantity to provide a floating or buoyant effect, by means of which the minerals were to be separated from the gangue. The idea was that the mineral sulphides, having a tendency to become easily oiled, would be caught and held in the oil sheet, while the gangue would not become oiled and would sink through the solution to the bottom of the containing vessel. This process was designed to be carried out in a slowly revolving tube or drum, by means of which the ore particles could be brought into contact with the oil cover without seriously disturbing or emulsi-

fying the oil. Naturally, the oil used must have been in large quantity—several times the weight of the ore itself. After the mixing process, separation was carried out in a spitzkasten or similar device. The process has had quite a large application in various parts of the world, but at the present time it has been discarded in favor of more economical processes. The bulk-oil process used a large quantity of oil, and there was some loss which could not be easily recovered. The process forms an important step, since it awakened interest in oil flotation and led to further important developments.

In 1902 Van Meter & Boss invented an oil process somewhat similar to the Everson, and although published results were good, nothing was ever done commercially with it beyond two installations in Peru.

Discoveries of Potter and Delprat.—An important invention in 1902 was that of Chas. P. Potter, who accomplished flotation in a 1 to 10% acid solution. By combining equal weights of ore and acid solution and heating the mixture, sulphides were caused to rise to the surface from which they were continuously skimmed off. The function of the gas was not mentioned but its actual necessity was undoubtedly realized. About the same time the Delprat process was invented by Guillaume D. Delprat, of Broken Hill, Australia, who accomplished the same results obtained by Potter, but by using salt-cake instead of acid. In each case bubbles of gas were generated which served to float the sulphides. Potter received priority of patent, though the process is usually known as the Potter-Delprat system. Both of these inventors proceeded to develop their processes and, from time to time, patented improvements. They soon found that a small quantity of oil was an advantage and made use of it.

Froment's Oil-Froth Discovery.—A discovery, which may be called of the greatest possible importance in flotation, was made by Alcide Froment, of Traversella, Italy, in 1901. He brought out the fact that, when small quantities of oil and acid are agitated in water with ore, the sulphide particles become preferentially oiled and attach themselves to gas bubbles and float to the surface, the gangue particles declining to receive the oil and sinking to the bottom of the solution. Froment desired to increase the quantity of gas, and to do this added small quantities of calcite, which, in combination with the acid, developed

carbonic-acid gas, with which the bubbles were filled. The importance of this discovery cannot be overestimated, since most of the modern and largely used processes are based on the preference of oiled sulphides to adhere to bubbles and rise to the surface, while the gangue acts in a contrary manner.

In about 1903 the Cattermole process was invented. This was not a flotation process, but made use of oil, and for this reason is interesting enough to be considered in connection with oil-flotation processes. In the Cattermole process a quantity of oil varying from 4 to 6% was added to a flowing pulp, producing a tendency to oil the sulphides and make them stick together, forming large and heavy globules or granules. These granules were heavy enough to fall to the bottom and remain in a pulp current while the gangue was washed away. In this process we have the spectacle of an oil-concentration system which was not flotation, but the exact reverse—in other words, gravity concentration carried out by a new method.

Another pair of inventors, Goyder & Laughton, brought out the underlying basis of the Potter-Delprat acid flotation system in 1903. Their invention was a machine instead of a process, but it was not very largely used, although it was tried at several plants in the Broken Hill district of Australia. In 1903 Jacob D. Wolf brought out another method of applying flotation principles. He used an oil to secure a high concentration of low-grade concentrates in the first step and by washing this concentrate with hot water to increase subsequently its grade. He also used steam to blow into the tailings, which raised to the surface globules of oil that had been lost, and with them some sulphide was also recovered. No practical application of the patent has been made so far as is known.

The Elmore Vacuum Process.—In 1904, Francis E. Elmore figured again in the oil-flotation field through the patent he secured for a system of vacuum oil-flotation. In this, flotation was accomplished by raising the mineral to the surface of the pulp in a froth and the froth was formed by the addition of a small quantity of oil and by liberation of the air in the pulp itself in a fine state of subdivision. The liberation of this air was accomplished by applying a vacuum to the pulp and warming it, by which means the air dissolved was released and, attaching itself to the slightly oiled mineral particles, raised

them to the surface. It may be noted that about 2.2%, by volume, of air is dissolved in water at normal temperature and pressure. When the pressure is lowered and the temperature raised, that air is released, forms bubbles which serve to form a froth just as in the agitation processes. The amount of air self-contained in the water may be computed to have a certain definite lifting power, and in the development of the probable possibilities the theoretical indication is that 360 lb. of the Broken Hill, Australia, zinc-lead sulphide may be raised to the surface by the amount of air contained in a pulp consisting of 1 ton of ore to 6 tons of water. These figures are given by T. J. Hoover in "Concentrating Ores by Flotation," page 102. It may be noted, however, that in actual practice the weight of sulphide that is floated is considerably greater than the theoretical capacity based on the efficiency of air released from solution in the water. Undoubtedly some of this additional work is done by the gases liberated by the action between acid and carbonate, but there is an additional reason for the discrepancy, and this matter will be discussed in the chapter dealing with the theory of the process. The quantity of oil used in the Elmore process was gradually reduced to about 10 lb. per ton and finally to 3 lb. per ton of ore. The machine, to which the success of the process is largely due, was an ingenious device designed and built by Elmore himself. It was used with notable success at the Sulitelma copper mine, in Norway.

The De Bavay process is one in which a thin film of flowing pulp is brought to the surface of a vessel of water where advantage is taken of the surface tension of the liquid and the sulphide is floated. This process was patented by Auguste J. F. De Bavay in 1904. De Bavay mentions the fact that if the surface of the sulphide particles is coated with a film of carbonate from weathering, this is a detriment to the process and should be removed by soaking the ore in a weak solution of ammonium carbonate. The same effect can be had by passing carbonic-acid gas through the pulverized wet ore, or by so grinding the ore that the undesirable surface shall be removed by attrition. This process was installed in one or two places in Australia and is said to have been a success. The method has, since its inception, undergone a great many changes, and its users are now employing small quantities of oil to assist in extraction.

Another patent, in 1906, that of James H. Gillies, was applied on a commercial scale in Australia. Although this process makes use of the principles of Potter and Delprat, the apparatus was unique. The plant was a failure economically and the process has been abandoned.

The Macquisten Tube Process.—In the chronology of the important patents, we now come to that of Arthur P. S. Macquisten, taken out in 1904, in which he set forth a process and tube apparatus which made use of surface tension for separating the minerals, whereby some of them floated and some sank. The apparatus was new and important, but the principle upon which it depended was the well-known one of surface tension. The process was first installed at the Adelaide Reduction Works, Golconda, Nev. In 1911, the Federal Mining & Smelting Co. installed 119 of the Macquisten tubes at the Morning Mill, at Mullan, Ida., for treating middlings containing blende, galena, siderite and quartz, and the results, while not altogether satisfactory, were of sufficient value to insure the continuous use of the tubes, and they are running to this day and doing good work. The capacity of the installation is about 150 tons per day.

The next important process is that known as the Murex, invented in 1908 by Lockwood and Samuel, and is a process for making sulphide particles more magnetic by utilizing the selective action of oils. In 1909 they described their method of increasing the selective action of oil by treating it with various soluble salts, and also a process through which magnetic or magnetizable substances are added to an ore pulp, the whole being treated with an oil to cause the sulphide and the magnetic particles to adhere together. The oiled sulphides are then removed from the pulp by means of a magnet. Plants following this process have been erected and operated with some success. The process is not flotation, but since it uses oil and since the desired results are somewhat the same, it is of sufficient interest to be noted here.

James M. Hyde's Process.—In 1911, James M. Hyde brought out a flotation process in which a small amount of sulphuric acid, with or without the use of iron sulphate, was used to give the slimy portion of the ore a preliminary coagulation before bringing it to the flotation machine, and in which the sulphide, after agitation, was floated off rapidly and as com-

pletely as possible with a considerable overflow of freely flowing water. This thereby produces an impure concentrate that is retreated in a second machine, from which only high-grade concentrate is taken off, with no free-flowing water. The process has been adopted by the Butte & Superior Copper Co., of Butte, Mont. It has been in use at this mill for a number of years, and its principal importance is due to the fact that it constituted the first basis for litigation, the fact being that Minerals Separation sued James M. Hyde for infringement of its patent in the application of flotation to the Butte & Superior ores. The Butte & Superior ores consist of blende widely disseminated and finely divided in a quartz gangue.

A step of importance is J. M. Callow's American patent for his pneumatic machine, which was taken out in July, 1914. Some authorities claim that Callow's idea is the same as that appearing in T. J. Hoover's British patent No. 10,929 of 1910, now the property of Minerals Separation. It has also been said that R. S. Towne used the same idea earlier than Mr. Callow in the form of a carborundum wheel, the central hole of which he plugged so that the wheel served as a porous bottom. Whatever the merits of the discussion may be, the fact is that Callow has succeeded in developing an important variation of the flotation process, and his means of applying the principles, whether they infringe anything else or not, is an effective one in many cases.

While discussing the various flotation processes, it may be well to mention that of Wood, of Denver, who has, although not bringing forth any new process, developed a machine which takes great advantage of some of the surface-tension principles, and is so different from the rest as to be entitled to some mention. In Wood's method, the ore is crushed dry to pass a 30- or 40-mesh screen and is then fed in a thin stream from the vibrating plate onto the surface of water in a tank, to the surface of which a forward movement is given by small jets, also of water. By a combination of the capillary attraction and the pressure of a constant feed, the sulphides are caused to move forward as a definite elastic film on top of the water. This film of mineral passes over an endless canvas belt, which emerges from the tank at a particular angle, varied according to the kind of mineral to be saved. The belt, with its film of sulphides, passes over three

rollers so that its motion is reversed and it strikes the water-level of the second tank, where it releases its valuable burden. Very little gangue in suspension comes over, and the water drains back into the main tank. Any submerged particles that have been accidentally wetted or so heavy that they have penetrated the surface film, pass to standard concentration tables, on which they are separated by gravity in the ordinary way. In the case of molybdenite and graphite, the film concentrate is still further cleaned by being passed over a nearly vertical screen. Gangue in suspension passes through while the flat crystals of the valuable minerals slide over the screen, thus largely dewatering them. The flotation concentrate is collected and dried as usual. The Wood process has been used in many cases and at the present time seems to be largely successful.

Bradford's Preferential Separation.—Leslie Bradford, of Broken Hill, Australia, has patented a process of preferential flotation for the treatment of mixed sulphides, adding certain mineral salts, such as thiosulphates, to the water used in the flotation cells. The *Australian Statesman and Mining Standard,* of July 22, 1915, says that the distinguishing feature of the method consists in treating the ores or ore products in a medium which wets zinc sulphide and does not wet lead sulphide or pyrite and therefore leaves the last-named sulphides floatable while rendering the zinc sulphide temporarily immune to flotation. The lead sulphide and any pyrite are thus obtained first as float concentrates; thereafter the residues comprising gangue and zinc sulphide are treated for the separation of the zinc sulphide from the gangue.

This "wetting" effect, according to the patent specification, is procured by adding to an acid flotation solution a limited quantity of a substance which is decomposed by said solution, and produces in this decomposition a reducing gas which is more or less soluble in the solution. Notably thiosulphates, sulphites, and bisulphites are so decomposed in a solution of sulphuric acid with the production of such a gas (sulphur dioxide). With substantially equal result, sulphur dioxide may be introduced directly into the solution, either as gas brought into it in a current or added in solution. The like effect is obtained by means of another reducing gas, sulphureted hydrogen, which may be similarly introduced into the solution or may be produced in it

by adding sulphides or polysulphides which the solution is capable of decomposing.

In practice a limited quantity of such a reducing agent is introduced into the solution, prior to flotation treatment of the ore therein, with the object of procuring this zinc "wetting" effect. The reducing agents preferred by the inventor are thiosulphates, sulphites, and bisulphites, as they are usually more effective than those belonging to the second group.

In the actual application of the invention to a Broken Hill mixed-sulphide ore containing zinc and lead sulphides, the flotation operation is considered in a plant of the type described in two previous Commonwealth patents, using the flotation boxes set in series, and treating ore at the rate of 25 tons per hour. No serious difficulty is experienced in correctly proportioning the sodium thiosulphate (the blende "wetting" agent) so as to insure the rapid floating off of the galena substantially pure or as a high-grade concentrate rich in silver, and to leave the residue in a condition suitable for further flotation treatment for the recovery of the zinc sulphide therefrom.

The flotation treatment is preferably conducted according to the froth-flotation principle; the procuring of the effect aimed at is dependent upon the presence of a frothing agent in the flotation medium, only when a reducing gas is introduced into the medium; it is not dependent upon the presence of a frothing agent in the flotation medium when a reducing gas is generated in the flotation medium by reaction of a substance introduced into it. In some cases enhanced results are obtained by digesting the ore with sulphuric acid and the reducing agent in a thick pulp, prior to subjecting the same to a flotation operation.

In the foregoing discussion, practically all of the processes making use of real differences of principle have been mentioned. All of the machines invented for taking advantage of these principles have by no means been mentioned. There are shoals of them, and each week brings forth new claimants for attention. The merits of these machines, however, will have to be worked out in practice, and, aside from the ones already mentioned, there is nothing important enough to be in this section, although in the further description of the process herewith, many of them will be described.

Emphasis should be placed strongly on the fact that I have

made no attempt to catalogue all patents that have to do with flotation. Only those that seem to be of practical importance in relation to subsequent commercial work have been mentioned and, no doubt, interesting ones have been omitted. No attempt has been made personally to search the patent records, but dependence has been placed on the literature, such as Hoover's original book and the files of the technical press.

CHAPTER III

THE THEORY OF FLOTATION

The most peculiar fact about the flotation process of ore concentration is that in spite of its rapid development and wide application to metallurgy, the practical results obtained have not been built up as a result of the application of a definite theory, but have rather disregarded basic reasons and grown upon the practical physical facts derived from experimentation. The theory of the process, up to this time, has been uncertain and none of the tentative theories so far proposed has been sufficiently elaborated and discussed to prove entirely satisfactory. The surface-tension theory, undoubtedly a primary basis of some flotation phenomena, is believed also to account for the production of froth by the use of oil through the fact that oil reduces surface tension of liquids and allows bubbles of a more permanent character to be formed. While partly explaining the phenomena, this one physical fact will not account for all the results that come through all kinds of flotation processes.

Surface tension has been elaborated in the discussion of theories by Hoover * to describe its effect and its influence upon the flotation process. He points out that all masses of substances, whether solid, liquid, and probably gases also, have acting at their surface a force parallel to the surface that is the resultant of molecular activity within the body of the substance, and that tends to resist rupture of the surface. In the case of a liquid this force is known as surface tension and in the case of some liquids the force has been measured. In Hoover's description, it is noted that for the surface of plain water in contact with air, the magnitude of this force has been determined to be 81 dynes per linear centimeter.

Discussion of Surface Tension.—It may be better, however, before going into a detailed examination of surface tension, to examine the explanation of that force.

* "Concentrating Ores by Flotation," First Edition. Page 49.

W. R. Ingalls* says that a body of water, or of any liquid, has greater cohesion in its free surface, *i.e.* the surface exposed to the air, than anywhere else in its interior, because, whereas the particles in the interior are mutually attracted by adjacent particles in all directions, those at the surface have no attraction from the outside—from above, let us say—to counteract the pull from those in the interior. This condition may be illus-

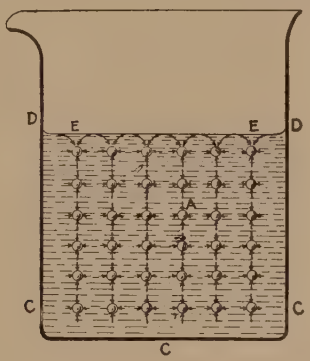


FIG. 1.—AN ILLUSTRATION OF SURFACE TENSION.

trated in diagrams by the accompanying sketch adapted from Hoover's book. The molecules of the liquid are imagined to be of sufficient size to be represented on paper, and in the drawing each circle represents a molecule. I quote this explanation directly from Hoover:

> The molecular attraction of each molecule can be resolved into resultants for purposes of illustration, the resultants being placed as shown by arrows in the figures. To make the assumption complete we must imagine two resultants acting at the center of each circle, at right angles to the plane of the drawing. The molecule at *A*, for instance, attracts and is attracted by adjoining molecules by resultant forces that are equal, and the molecule is free to move in all directions. The molecule at *B*, however, having no molecule above it to attract and be attracted, is in a somewhat different state. The molecule at *B* has its upper one of the fixed resultant forces uncompensated by a molecule lying above it, so we can assume that this upper resultant is compensated between the molecules on any side of *B*. This gives the top-

* *Eng. and Min. Journal*, Oct. 26, 1907. Page 765.

most row of molecules a stronger attraction for each other than the molecules adjacent to *A* have for one another. The attraction of the molecules within the liquid, as for instance those at and adjacent to *A*, is known as the force of cohesion. If this force of cohesion is resolved into the six resultants, as above described, and its magnitude is called 6 units, then the magnitude of the molecular attraction acting on a molecule in the top layer, as at B, will be six units just the same, but the molecule will not be as free to move in every direction as the molecule at *A*. If the stress between any two molecules in the horizontal row containing *A* is 2, then the stress between any two molecules in the horizontal row containing *B* will be 2½.

Ingalls goes on to say in explanation: "The effect of this is to reduce the mobility of the particles on the surface. The surface, as it were, is stretched by an elastic skin, the effect being the same as if the surface layer exerted a pressure upon the interior. The production of this surface tension represents energy, *i.e.* molecular energy, which may be measured."

As has been quoted above, this surface tension has been determined for water to be 81 dynes per linear centimeter, a force that resists penetration from within or without the liquid.

Surface Tension in Everyday Life.—The effects of surface tension are apparent in a great many of the ordinary appearances of modern life. So common are they that no attention is usually paid even to their most wonderful manifestations. Some of these ordinary occurrences are described by T. A. Rickard, in a paper he presented at the March, 1916, meeting of the Canadian Mining Institute, at Ottawa. Descriptions of the force and its manifestations have been voluminously described by various writers in the technical press of the last year or two, but it may be assumed that to the reader deeply interested in the theory of flotation, these illustrations are hardly necessary, so they will be passed over at the present time and more attention will be given to the purely practical phases of the subject so far as we know them. The many articles already referred to form a sufficient and satisfactory basis for any one who cares to, or needs, an elementary explanation of the phenomena. Will H. Coghill * presents an argument disagreeing with the previously made explanations of surface tension. He refers to the book on "Surface Tension and Surface Energy," by Willows and

* *Min. and Sci. Press*, Feb. 29, 1916.

Hatschek, which shows how the elastic-film analogy of the study of froths may get the student into trouble if not handled with care. He draws attention to the theory of surface tension, which is explained, or rather illustrated, by the analogy of the stretched rubber film. Analogies of the kind are liable to become destroyed if pressed too far, although they are useful up to a certain point. This one, says Coghill, is no exception. In the case of India rubber it is obvious that a given weight can only stretch this to a definite extent. To further enlarge the rubber film, an additional weight would be required, while with the liquid film this is not true. As to the breaking of the film, this depends, according to Coghill, not upon the surface tension, but whether or not there is enough liquid to supply the added area for enlarged bubbles. The difference between a non-aqueous substance and a liquid film is that in stretching the former the molecules are distorted or separated, while in stretching a liquid film the molecules come from within the liquid to occupy the new area. According to Devaux, the surface-tension phenomena disappear as soon as there is no more liquid to come from within. The same laws apply to surfaces that are allowed to contract. The rubber has a constantly decreasing force of contraction as it approaches its original dimensions, while a liquid film always tends to contract with the same force independently of its size. It is a common practice in demonstrating physical principles to omit certain qualifying conditions until the main features are outlined. This method must be pursued here. The qualifying statement is that in the case of a contaminated liquid the film may not contract with a force independently of its size; that is, after learning to look upon surface tension as a constant force, we must now view it as a variable one. Coghill apparently believes that variable surface tension is to be accounted of importance in froth formation, rather than uniform reduction of it.

Surface-Tension Processes.—The descriptions given here of various interpretations of the phenomena of surface tension are presented with a view of pointing out the trend of opinion on the subject. Undeniably for such processes as the Macquisten and Wood, where minerals are floated upon water surfaces without the addition of oil or other chemicals, the actual surface energy is probably the principal force concerned. Here the mineral particles are deposited with care upon the water sur-

face, and due to the surface tension and the property of minerals to present a contact angle of a certain degree (which is the same as saying they are non-wet), these minerals float. The siliceous gangue does not float, a fact that is due to the inherent tendency of such particles to possess an angle of contact of a decidedly less degree, as a result of which the particle is wetted, the surface film is ruptured, and the particle sinks.

When one speaks of flotation by means of the air-froth method as depending upon surface tension the statement is, perhaps, accurate, but it is not always clear whether the one making the explanation in such terms is clearly aware of the force of his statement. The forming of a froth has nothing necessarily to do with floating minerals. One experimenter reports that he can form a very voluminous froth with saponin, but gets no metallurgical separation by it. The minerals do not adhere to this froth, but will sink through it just as readily as siliceous particles will. Saponin "kills" the froth made by oils. The actual flotation by froth involves the same force, and when all points are reviewed carefully, it will be seen that the application is merely another phase of the same forces, applied in a slightly different way.

Unexplained Forces.—Froth flotation depends in part upon adhesion, and although it may be proved that this statement is technically accurate, it is very difficult to go back of it and explain what adhesion is. The manifestations of adhesive force are as clear and evident as those of the force of gravity, and just as unexplained. When an oil is added to a mineral-bearing pulp, there is a certain definite tendency for the oil to form a film upon the mineral particles, and there is a certain definite tendency for them to float upon the surface of the bubbles. To these tendencies the metallurgical world is indebted for the flotation process of ore concentration. These forces have not been really explained, and no matter how many words may be expended upon an effort to clear the situation, the facts must simply be taken as they exist, in the present state of our knowledge.

Electrical Surface Charges.—A word may be said here in reference to the often repeated statement that electrical charges upon the surfaces of the solids have something to do with the phenomena brought about by flotation conditions. It has been

shown that there is a connection between the charge on a particle and its contact angle, thus affecting the degree of wetness, but circumstances are such that explanations can be better made on some other basis at this time. It is true that particles of any size may, and probably do, carry electrical charges of some kind, since in most cases such charges may be measured under proper conditions, and these surface charges in the absence of other films may have much to do with the physical action of the particles, but conditions in ordinary work are not such that this force can be considered of commercial importance.

The Matter of Colloids.—The mention of colloids brings us face to face with another problem, the elucidation of which has much to do with a proper understanding of flotation theory. The metallurgical world is indebted to E. E. Free,* who has given us a view of what colloids really are and what can be done with them. Quoting from Free's article, the following is of interest:

. . . we have developed a conception of colloids that regards them simply as suspensions of very fine particles. The misconception of colloids as specific gelatinous substances possessing unusual quasi-chemical affinities we have criticised because it rests upon unsupported hypotheses and because it is unnecessary and confuses a matter not otherwise obscure. We have made no sharp distinction between suspensions and colloidal solutions. The emphasis, indeed, is quite the reverse, and is on the unity of this theory rather than on any possible severalty. As always, our insistence is upon properties rather than substances. Certain colloidal properties, among which we have emphasized slowness of settling and imperviousness of the settled mass, characterize suspensions of finer grain. These we call colloids. The distinction is purely relative. We mean that these suspensions are more colloidal than those usually encountered.

. . . Several other properties are of interest and deserve brief review. Most important scientifically are the similarities to, and differences from, the true or ordinary solution, the particles of which are supposed to be of molecular or ionic dimensions. The typical colloidal solution resembles a true solution in being permanent so long as conditions remain unchanged. That is, the particles remain in suspension and the colloidal solution retains an unchanged chemical composition. The colloids differ in failure to show a true and constant solubility; an optical heterogeneity shown by translucence or tur-

* *Eng. and Min. Journal*, Feb. 5, 1916, and subsequent articles.

bidity; the causing of no change or very small change in the freezing point and boiling point of the solvent; the production of no osmotic pressure; slow diffusion and failure to dialyze or pass through a parchment membrane. The causes of all these differences will be evident on consideration of the difference in particle size which distinguishes the colloids from the true solution. Details need not be pursued further than to say that the differences, as before, are of degree only. Colloids do not fail entirely to show the typical solution properties, but they do show them to so slight a degree as to escape all but the most painstaking and exact researches.

Of other properties of colloids, flocculation and absorption are mentioned. Another of much technical importance is the tendency of the colloidal particles to wander in the electric field and accumulate at one or the other of the poles. This is distinguished from ordinary electrolysis by the fact that the passage of current is not essential. The matter is one of electrostatics and occurs in non-conducting media. It forms the basis of the well-known Cottrell process for the collection of acid and smelter fume, the removal of dust from stack gases, the separation of oil globules from condenser water, and the like.

In Free's definition of colloids he has, by inference at least, limited it to solids. This is legitimate for our purpose, since it is with solids—ores—that we are concerned, but it is not general. W. D. Bancroft * says that "we call a phase colloidal when it is sufficiently subdivided, not limiting ourselves definitely as to what degree of subdivision. Colloid chemistry is therefore the chemistry of bubbles, drops, grains, films, and filaments."

Colloid solutions can be prepared by precipitating the substance from vapor or true solution in a finely divided form, or by disintegrating a mass of the substance in some way, mechanically, chemically, etc. *Stable* colloidal solution cannot be produced by subdivision alone. To keep particles from coalescing there must be either a material film, such as gelatine, or an electrical charge due to an absorbed ion, except under special conditions.

Having thus acquired a conception of what colloids are, we can now attack the problem of colloids in flotation. The colloid condition is not favorable to commercial flotation, a fact that experimenters who have been trying to float precious-metal slimes have come into contact with rather forcibly. Matter in solution cannot be subjected to flotation (at least, within the

**Jour. Phys. Chem.*, 18, 549 (1914).

limits of the practice of the subject under discussion), and it might seem, too, that colloids would also be outside flotation influence, but W. D. Bancroft * has shown that under proper circumstances some colloids may be easily floated.

"Isobutyl alcohol was added to a colloidal gold solution obtained by reducing gold chloride with carbon monoxide. When the two liquids were shaken the gold forms a thin film at the interface. This film is violet blue to blue green by transmitted light and golden by reflected light. A thin water film forms between the isobutyl alcohol and the glass, and the gold concentrates in the dineric interface thus formed, making the alcohol appear uniformly gold-plated. With ether the gold film rises high above the level of the two liquids. With carbon bisulphide the adherent film of gold appears blue. When the carbon bisulphide is broken into drops by shaking, each drop appears blue. When a blue gold was obtained by reducing gold chloride with phosphorus dissolved in ether, the gold went into the dineric interface. When a brownish-red gold was obtained in this way, it remained in the water phase and showed no tendency to pass into the interface. This difference is undoubtedly due to an adsorption of something at the surface of the gold, because Reinders found that 0.005% gum arabic prevents colloidal gold from passing into the ether-water interface. With carbon tetrachloride, carbon bisulphide, or benzene, the gold goes into the interface as before, but the gum arabic prevents its changing from red to blue.

"Colloidal arsenic sulphide goes into the dineric interface with amyl alcohol or isobutyl alcohol, but stays in the water phase when carbon tetrachloride, benzene, or ether is the second liquid. India ink goes completely into the interface with amyl alcohol, carbon tetrachloride, or benzene; it goes partly into the interface with isobutyl alcohol, and stays entirely in the water phase when ether is the second liquid."

The Matter of Emulsions.—Now building upon this foundation, attention is called to the inaccurate use of a word that has appeared so often in recent contributions to the science of flotation. Writers on the subject frequently refer to the combination of pulp, oil, water, acid, or whatever other chemical substance is added to it, as an emulsion. Going back to the defini-

* *Met. and Chem. Eng.*, June 1, 1916.

tion of an emulsion, we find that it is a colloid suspension of one liquid in another. For example, the oil in a mixture may be so finely subdivided as to approach the colloid state and simulate a true emulsion. If, as has been said, the colloid condition is antagonistic to flotation success, then this pulp-oil combination is not a true emulsion, since we clearly do get flotation results from it. The latter statement is true—it is not an emulsion.

The physical evidence of the non-colloid condition of the pulp subjected to flotation conditions is that of a mixture and not an emulsion. In undertaking a careful study of these conditions, we are again indebted to Free, who, in the series of articles already mentioned, has given a clear exposition of these conditions under the subject of "Sedimentation and Flocculation." * Here he has pointed out the factors that tend toward flocculation and those tending toward deflocculation. Among the flocculating agents is mentioned sulphuric acid. Now, since a true emulsion is a colloid condition, it is also a deflocculated condition. A deflocculated condition does not commonly exist in the presence of sulphuric acid. The deflocculated, or colloid, material remains as a more or less permanent suspension, and flotation conditions have no effect on it. We have therefore the interlaced and interdependent facts that a flocculated condition is desirable for flotation, while deflocculation is a requirement of emulsion. Sulphuric acid is usually a flocculating agent; therefore, emulsions are not to be expected when sulphuric acid is present. It is extremely probable that the sulphuric acid, a flocculating agent, is mainly used to prevent the colloid or emulsion condition, although a great many other reasons have been given for its use. The undesirability of the emulsion condition of oil in flotation and the function of sulphuric acid in preventing emulsification was first pointed out in the work of G. D. Van Arsdale. Among the other reasons given for the employment of sulphuric acid may be mentioned that of cleaning of the surfaces to permit the adhesion of the oil film to a mineral or metallic surface. Apparently, however, the amount of acid commonly used is too small to have any active chemical effect in such a bulk of water and solids, but is in quite sufficient quantity to act as a flocculating agent. Hence, in speaking of

* *Eng. and Min. Journal*, March 4, 1916.

the pulps used in flotation, they should be referred to as mixtures and not as emulsions.

There are of course differences in the character of emulsions, and these differences depend upon the character of the liquid that approaches the colloidal state. Many emulsions are such that when set aside the finely divided particles of oil coalesce and separate from the solution mass, while others are of such character that the colloidal condition is maintained and the fine particles do not coalesce or separate even upon long standing. It may be shown that oils in the colloidal state, or emulsified, do not promote flotation. Apparently their effect upon the actual surface tension of the liquid is the same as when in any other condition, but when in the colloidal state these oils develop physical characteristics that tend to force them to maintain that condition and therefore the oil particles remain suspended separately and refuse to oil the mineral particles. Apparently the intersurface forces set up preclude the selective action of the oil upon the minerals, and therefore no flotation results. However, if a truly emulsified oil in pulp is treated with sulphuric acid, tending to flocculate the oil, the selective quality of the oil-mineral combination comes into action again, and flocculation conditions are reëstablished.

The Degree of Flocculation.—It may be said, quoting again from Free,* that the degree of flocculation is extremely sensitive to surrounding conditions; so sensitive indeed that changes of flocculation in the true colloidal solutions are among the most delicate of analytical reactions. These changes and similar ones in the coarse suspensions may be caused by many kinds of influences. Temperature, light, the radiation from radium, electrostatic charges, and many other variations in energy relations all appear to have perceptible effect. However, these effects of direct energy changes are far less important practically than the effect of added substances, and it is these latter alone that require consideration in a practical examination of the subject. A large amount of observation and incidental experiment, going back for many centuries, has sufficed to establish three general classes of substances which affect this degree of flocculation, or, as it is generally conceived, the rate of settling of suspensions.

* "Sedimentation and Flocculation," *Eng. and Min. Journal,* March 4, 1916.

First are the neutral, inorganic salts and the inorganic acids, all of which increase the degree of flocculation and promote settling. Second are the alkalis, which (in certain concentration) have the reverse effect, decrease the degree of flocculation, hinder settling, and are known as deflocculators. Third are the organic colloids of the liquid-particle type (emulsoids) such as gelatin, albumen, and the like. The effect of these is somewhat complex, but in general they also decrease the degree of flocculation, or at least prevent its increase.

A careful explanation of how flotation takes place has been worked out by G. D. Van Arsdale.* He prefaces his argument with the statement that it is easier to tell how flotation works than why, and consequently he leaves out any attempt at basic reasoning, but does show the actual uses of the various processes employed. In the pages immediately subsequent I shall follow Mr. Van Arsdale's line of argument in the main.

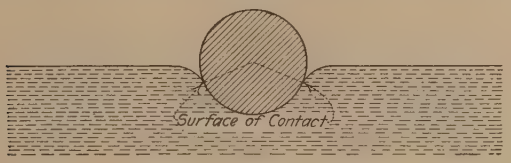
Mutual Surface Action.—It is not so easy to give an actual definition of flotation, but it is possible to say that it is concerned with the mutual action of the surface of solids, liquids, and gases, and that the surfaces of various solid particles behave differently with respect to the surfaces of liquids and gases. It is possible, using this definition, to classify practically all the known methods of flotation. The first class makes use of the surface of one liquid and is exemplified by the Wood and Macquisten systems. The second class employs the surface of one liquid and of gas bubbles, and includes the Potter-Delprat method. The third class utilizes the surface of two immiscible liquids, and is exemplified by the first Elmore process. Class four is the utilization of the surface of two immiscible liquids with the addition of gas bubbles; this class includes the modern oil-flotation methods.

The froth, which is one of the most prominent features of ordinary flotation methods, is a collection of bubbles, and a bubble consists of a liquid surface in contact with gas, which in some cases it entirely incloses. This definition connects the basic theory of froths with the process used in class one, since the conditions are the same—a liquid surface in contact with a gas. In other words the froth utilizes ordinary surface-tension forces.

A particle heavier than water can only float upon a watery

* "How Flotation Works," *Eng. and Min. Journal*, May 13, 1916.

surface because of the effect of surface tension. There is a definite relation between surface-tension factors and the maximum weight that can be supported on water surface, and this has often been quoted in the statement that one square centimeter will support about 81 mg. As a matter of fact, Mr. Van Arsdale shows that a square centimeter will support much more than this weight. The desired relation can be derived from the surface-tension formulas for the difference in pressure between two kinds of a curved surface and these formulas are shown in the accompanying figure. By their use the maximum size of cylinder and sphere that will float can be derived, and as a mat-



Sphere, $P = \frac{T}{R}$; Cylinder, $P = \frac{2T}{R}$

FIG. 2.—THE SURFACE CONTACT DIAGRAM.

ter of fact clean copper wires of a size very close to that calculated can be floated, indicating the correctness of the hypothesis. The length of the wire should make no difference according to the theory, and in fact, a long wire floats just as well as a short one.

The question of influence of the shape of the particle can be answered by referring to the same formula. It can be seen from them that with equal radii and surface of contact the specific gravity of a maximum-sized floating sphere may be twice that of a floating cylinder, showing that the shape of the particle is an important consideration.

Effect of Surface Films.—The other conditions to be taken into account are the presence or absence of surface films on particles, the kind of films, and the resulting contact angle produced by them. It is perfectly evident to all acquainted with flotation that films of various kinds on particles may prevent or produce flotation. A clean copper wire floats. The same wire having an oxide film sinks promptly, while the same wire, again, with a sulphide film floats easily. Mr. Van Arsdale points out

that the reason for this difference in floating ability is the character of the contact angle produced by the film, but W. D. Bancroft is inclined to question the possibility of measuring a contact angle with any degree of accuracy and therefore is not sure that a specific contact angle for a substance exists, but is variable widely due to many conditions. As a matter of fact, however, these films do have the effect of promoting or preventing flotation; and such films may be extended to include charges of electricity, theoretically, at least. In continuation of the contact-angle theory, Valentine has set forth, theoretically and by practical tests, that one of the flotation factors is the contact angle, which must be of a certain degree to make floating possible. The film, as has been said, may be solid, liquid, gaseous, or even an electric charge. The use of oil in flotation practice exemplifies the liquid film, which will produce as definite results as the solid film. Particles of malachite converted to sulphide by the action of H_2S gas, if dropped on the water surface, float well because their contact angle is due to their having a strongly adhering surface film of gas.

Up to this point, the theory has been extended to several conditions of flotation, namely: surface tension, size and specific gravity of particles, shape of particles, and films and their resulting contact angles or whatever name may be applied to the effect produced by films upon particles which promote or prevent flotation. Any particle heavier than water may be made to float provided it is small enough, of proper shape with respect to size and weight, and has a surface, the resultant of which is a contact angle that permits flotation.

Surface Films and Gas Bubbles.—It is practically impossible to produce a surface free from a film of any kind, but it seems likely that for all such surfaces the contact angle with water would be zero, or it may be otherwise stated in that a perfectly clean particle will not float. It is of importance to know why gas bubbles attach themselves to mineral particles and not to gangue particles, and whether there is any particular virtue in the way gas bubbles are generated by the action of acid on carbonates of the gangue in such systems as the Potter-Delprat. If some mineral particles whose contact with water renders them non-wet are put into the bottom of a vessel containing pure water and a bubble of air is brought into contact with these particles, they

will become attached and the particles will be carried up to the surface with the bubble. This goes to show that it is not necessary to form the bubble in solution, nor is it necessary to have nascent bubbles or anything of the sort. The mere attachment of the mineral to the bubble, or the simple contact of gas and liquid surfaces is all that is necessary. In explaining why the bubble attaches itself to the mineral and not to the gangue, the accompanying sketch represents a largely magnified diagram of a bubble of air or gas in contact with two particles, one of the particles having assumed a contact angle that would enable it to float on a watery surface, the other particle having a contact

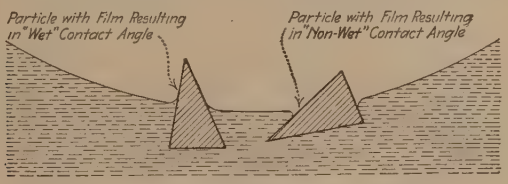


FIG. 3.—MAGNIFIED SECTION OF A BUBBLE.

angle that would produce immediate sinking on a water surface. Considering this diagram, it will be seen that the bubble is really only the surface of water in contact with air or gas, and that the particle floats on this surface for exactly the same reason given in the first class of methods. The fact that the system of bubble and particle is small and movable does not influence the surface tension and other factors that govern this kind of flotation. There is no attraction between bubbles and particles at a distance, but as soon as this surface comes in contact with the non-wet particle, it attaches and floats on the surface exactly as on a larger water surface.

There are some other methods whose action bears directly on modern processes, and among them may be mentioned the bulk-oil or first Elmore process. This is explained in the fact that certain kinds of particles enter and remain in the oil, others remain on the surface separating the oil and the water, and others again enter and remain in the water. All three can be explained on the basis of surface tension together with other factors already mentioned, and Reinders has proved this both theoretically and practically.

Reinders's Statement of Inequalities.—"If we represent the interfacial tension between the solid and water as T (s, w), the tension between water and oil as T (w, o), and the tension between the solid and oil as T (s, o), Reinders stated that:

"If T $(s, o) > T$ $(w, o) + T$ (s, w) the solid powder will remain suspended in the water.

"If T $(s, w) > T$ $(w, o) + T$ (s, o) the solid will leave the water and go into the oil.

"If T $(w, o) > T$ $(s, w) + T$ (s, o), or if none of the three tensions is greater than the sum of the other two, the solid particles will collect at the boundary between the oil and water." *

These expressions will also hold true for a particle coming into contact with a film of oil instead of a layer or globule of oil, except that in this case the particle becomes coated with a film of oil or does not become so coated, instead of entering or not entering a layer of oil. It should be emphasized that the reasons for the action as shown by these illustrations are precisely the same as those given for the first two classes of methods—namely, size and shape of particles and the kind of film on such particle or absence of film, which produce by their presence or absence the resulting surface tension and contact angles.

Action of Oil.—The action of oil may be illustrated by experiment. A globule of oil is suspended in a mixture of equal specific gravity. A silicate particle coming in contact with this oil will not be wet by it, as may be seen by trying to stir about such a bubble of oil with a glass rod, which represents the silicate particle. If the same operation is carried out with a copper wire having an oxide film, the same result will be obtained, but if it is tried with a copper wire having a sulphide film it will readily be seen that the oil will definitely adhere to the wire and it is only with some difficulty that it can be disengaged, and when it is disengaged it will still leave a film of oil upon the wire. The reasons have been set forth in the inequalities of Reinders already mentioned.

What happens when a particle meets oil in the form of emulsion is not altogether clear, but it is very likely that there will be no attachment of oil to mineral unless some factors are introduced that will break up or destroy the emulsified condition, thus bringing out a fact that has already been referred to. Since

* From article by O. C. Ralston, *Min. and Sci. Press*, Oct. 23, 1915.

sulphuric acid is largely used in flotation, it is altogether possible that this is one of its principal uses. Further proof is found in the fact that substances that promote emulsification are disastrous to flotation. The accompanying table shows the effect of various agents upon emulsion.

EMULSION-MODIFYING AGENTS

Sulphuric Acid	0.244%	entirely prevents emulsification
Cresylic Acid	0.006%	entirely prevents emulsification
Acetic Acid	0.014%	entirely prevents emulsification
Citric Acid	0.066%	entirely prevents emulsification
Alum. Sulphate	0.06%	prevented emulsification
Copper Sulphate	0.30%	prevented emulsification
Ferrous Sulphate		No action
Caustic Soda	0.30%	No action
Sodium Chloride		Stabilizes and increases emulsification

As a means or mechanism for separation of mineral and gangue particles, the froth is, of course, simply a very largely extended surface as compared with the similar surfaces of water, and this extension of surface will be more or less proportional to the size of the bubble. If a space 6 in. deep above a water surface 1 ft. square is covered with bubbles, the amount of increased surface may be taken as roughly equal to the figures shown in the table given herewith.

SURFACE AREA OF FROTHS

1 Sq. Ft. of Froth, 6 In. Deep

Average Diameter of Bubbles	Surface Area at Least
1 in.	18 sq. ft.
½ in.	37 sq. ft.
¼ in.	75 sq. ft.
⅛ in.	150 sq. ft.

Qualities of Flotation Oils.—The question of oils comes in next and the object is to find out what use is to be specified for oils. Oils are, of course, used for two main purposes—first to provide a film around the particle and second as a means of making a foam or froth. We can then divide the oils into "oilers" and "foamers," and in practice a mixture representative of both classes is desirable. Of course, for oilers an ordinary cheap oil, possibly petroleum, can be used provided it supplies the necessary film upon the mineral particle. In the second

class of oils is needed one which reduces surface tension most. Professor Bancroft calls attention to the fact that an absolutely pure oil will not produce froth, and that the frothing quality of an oil is due to colloids in the oil. It may also be added to this statement that fine enough particles in the pulp will have the same effect, so that we may really have a froth made up of an oil having no colloids in it originally, the colloids' effect being supplied by the particles.

In continuation, Mr. Van Arsdale says that the result of the addition of the second class of oils is that a minute amount of any of them, such as crude pine oil, cresylic acid, etc., added to a surface of water upon which a film of oil of the first class is spread, will result in an immediate and striking retraction of the film. The oil then takes on, in most cases, a circular, globular form, with definite contact angles. This shows an important function of the addition of this minute amount of, for example, crude pine oil, is to change the surface tension and contact angle of the other oil or the particle coated by it, so as to enable it to float, which it otherwise would not do. Heat may apparently act in the same way, for if some oil is dropped upon the surface of hot water it does not film out but assumes a globular form.

If this reasoning is correct, it seems that instead of adding oils in a mixture it will be found more rational to separate them and add the proper amount of the first class to mixing apparatus or mill machinery, and then after having coated the particles, to add the second class of oil to the flotation apparatus. This ought to give better practical results, since it is evident that during the first operation it is necessary to have the oil in such a condition that its filming-out properties will be at a maximum, which will not be the case with a mixture of both classes of oil as ordinarily used. Along these lines it is possible to imagine that in some cases it may be possible to omit the frothing oil altogether, since, if with Professor Bancroft's ideas correct, the frothing is not due to the oil at all but to colloids that might possibly be supplied in some other way. As a matter of fact, as pointed out by Mr. Van Arsdale, it is not impossible that we may finally have a successful flotation without any froth, with its consequent power consumption, or even without the use of any oils.

CHAPTER IV

OILS AND THEIR USES

The oils used in the flotation process are many and their qualities vary within extremely wide limits, so that it appears that with ores of certain classes certain oils may be used, while with different ores oils having different qualities must be made use of in order to produce successful results. It has seemed apparently true that any particular kind of oil is not necessarily applicable to all ores, or perhaps it would be better to say that the same oil will not produce equally successful flotation results with all ores. That has been the theory heretofore and is an assumption that most metallurgists have taken for granted and have not seriously questioned. Apparently, however, the statement is not so broadly true as has been believed, and there are some who go so far as to say it is not true at all. The belief is not rare that an oil that will successfully promote flotation concentration on any particular ore can be used in making flotation concentrates on another ore, if the other conditions are so varied as to make them applicable.

Of course it is not intended to make the statement that all oils will produce satisfactory flotation froths, for it is well known that some oils produce good froths while others do not, but the point desired to be brought out is that an oil that makes a good froth in one case will produce froth in another case if the proper conditions are provided; that is, as to the nature of the pulp, solution, and combination of the two. The conditions of oil quantity and the presence or absence of a high degree of agitation must also be properly arranged to suit each case.

The Purpose of Oil in Flotation.—The exact function of oil in flotation is a point that has not yet been definitely settled. The primary function, which has been clear since the inception of the flotation process, is that the oil serves to reduce the surface tension of water and thus provide for bubbles and froth of more lasting character than could be formed without its use. In prac-

tice some operators have brought out the theory that only with the lasting bubble in the froth can the best results in flotation be obtained. If that, however, is the only use of oil, what shall we say about those surface tension and gas-bubble processes in which no oil is used, such as the Macquisten process, the Wood process, the Potter-Delprat, and others of like nature? In these cases flotation is successfully accomplished without the use of any oil whatever. On the other hand, the flotation processes that are used on the largest scale and the ones that are achieving the greatest success are those in which oil is used. It seems evident, therefore, that in addition to the function of reducing surface tension, which the oil undoubtedly does accomplish, there must be further work that it performs. One of the properties of oils, it may be pointed out, is their preferential adhesion to some minerals rather than to gangue particles. This is a fact that has been emphasized by a large number of experimenters and one that has been accepted as true up to a comparatively recent time. Now there are many who believe that there is no selective action whatever and that the difference in action of the oiled minerals and gangue particles is due to other forces altogether. In spite of this suspicious attitude, however, it seems almost certain that there is a certain preferential action, the oil adhering to mineral particles, particularly of a certain kind, rather than to the siliceous gangue particles of an ore.

Preferential Oiling of Mineral Particles.—A careful examination of a pulp containing oil that has been added for flotation purposes will show that the majority of the mineral particles are more or less oiled, while the great majority of the gangue particles do not carry oil. This is subject to some qualification, however, for oils of certain classes—vegetable frothing oils, for example—are to be found in the gangue and not in the mineral concentrates. Such condition is probably due to the solubility of these oils in water, since they are not to be found directly in contact with gangue particles, but in the pulp tailings. This subject will be treated in further detail later. Whether this adherence is due to preferential action between oils and mineral, one cannot at the present time definitely say, but the fact remains nevertheless. As to why the oil tends to prefer the sulphide particles, we cannot be sure. The reason probably depends upon the adhesion, which is one of the few forces of

nature upon which little light has been thrown so far by scientists. As a matter of fact, there are perhaps few who know much about adhesion, while to the majority of even the scientists the reason for it is as unexplained as, for instance, gravitation. We can certainly say nothing certain about the oiling of mineral particles that will throw any light upon the preference, if such exists, for the oil to coat the mineral particles rather than the gangue particles.

It is a well-known fact that there are surface forces that may change completely the tendency of bodies to act in any particular manner. If we assume it to be a basic fact that mineral particles do become oiled in preference to siliceous gangue particles, it is not so difficult to imagine that there would be a tendency between the oiled mineral particles and the oiled gas bubbles to remain in contact with one another, the buoyant tendency of the gas then tending to lift the mineral in the froth The well-known fact that solid particles carry electric charges, and that these charges in the mineral and gangue particles are or may be of different kinds, should be borne in mind in the elaboration of any theory of flotation or the function of oils in the process. The additional fact that these particles with electric charges migrate in the electric field, their direction varying according to the charge they carry, must also be remembered and may serve as a hint toward the preferential separation of minerals and gangue. In an ordinary dilute pulp this migration may be found to account for the fact that the minerals become more or less separated from the gangue, and may also help to explain why the minerals will take an oil film more easily and promptly, even if not to the entire exclusion of the gangue particles.

An objection to the electric basis for a theory of this kind, however, is found in the statement by authorities on colloids that this difference in electrostatic charge is a property of colloids only and does not apply to particles of practical size in suspension. Such particles, say these authorities, all carry charges of the same kind, and there would therefore be no tendency toward separation unless the oil film on mineral particles tends to change the character of the charge or to insulate the particle.

The surface films on particles will also have an important effect upon results. Surface films may be of four kinds—solid,

liquid, gaseous, or electric. In solid surface films we have as an example the limonite coating formed on various mineral particles —for instance, bornite—which more or less effectually prevents it from being successfully separated by flotation. It may be noted that if this surface film is changed or removed, flotation of the particles may take place. This is accomplished in practice by using an acid solution, or electrolyte, which removes the oxide, thus enabling the particles to be floated. The removal of this solid film may permit the oil film to be formed on the particles, which may account for its ready flotation under the changed conditions.

The Functions of the Oil Film.—Thus we see that there are at least two functions of the oil: First, to reduce the surface tension of the liquid so that a more permanent gas bubble may be formed, and, second, to preferentially oil the mineral particles so that some other effects, yet to be discussed, may be permitted to take place. The fact that the introduction of certain substances into the pulp solution may entirely change the effect of an oil is significant. Oils that produce a perfect froth under normal conditions may be so influenced that they will not produce a froth at all if certain substances are introduced into the solution. It may be noted that all of these substances are deflocculating agents—that is, such substances as will permit the oil to become emulsified and maintain itself in that condition. While it may still retain the property of reducing the surface tension of the water through solubility or miscibility, and may permit the formation of bubbles (although this is not usually the case), the emulsified oil is still in such condition that it apparently cannot effectively oil the mineral particles, or perhaps any particle, so that its function will not be sufficiently well performed to enable it to be of use in promoting a flotation concentration, as has been pointed out by Van Arsdale, mention of which is made in the chapter dealing with the theory of flotation.

As to the service performed by the oil film on a mineral particle, reference to recent discussion on the theory of flotation indicates that a prime requisite for the flotation of a particle is the presence of a surface film having the property of refusing to be wet by water. The oil usually provides this film. The surface-tension theory of flotation necessitates the presence of this non-wet surface.

To provide a non-wet surface on the mineral particle, the oil used to supply the film must be such that it will not be wet by water, or some constituent must be added to the water that will prevent it from wetting the oil. Most oils will not be wet by water, but some of them will, and the latter are not suitable for use in flotation unless something be added to the water to prevent the wetting action. Some acids supply this quality. If we attempt to explain the quality of an oil to be wet, or not, by water, we come again to the insurmountable barrier of adhesion phenomena, which alone can explain that quality.

It is to be remembered, however, that in spite of all this talk about oils and their effect, they are not the only materials that can form a non-wet film on solids. There are some solids that will do it; perhaps some gases, and not impossibly, electric surface charges. It has been shown that colloidal films of some kinds may be so manipulated as to produce this result.

Oils in general, then, may be divided into two groups, the first containing those oils whose duty it is to provide the non-wet film on the surface of the particle; and frothing oils, which serve to make the froth possible by reducing the surface tension by water.

Coal Tar as an Auxiliary in Flotation.—It is unfortunate, but true, that at the present time the realization of the functions that oils have to perform does not give us any advance information as to what kinds will be suitable to certain ores. So far it is altogether a matter of practice, the old rule of cut-and-fit being the only one from which much practical information can be derived. Every flotation plant finds an oil particularly suited to the ore being treated if the experiments are carried far enough. There seems to be no one oil that will give equally satisfactory results in every case. Coal tar may, however, become a universal oil when employed as a base for making good working mixtures of oils.* Until the latter part of 1914 the principal oils utilized for flotation in this country for copper ores were wood distillation products and cresol. The price of cresol, about 30c. per gal., has made its use costly, even though as little as two pounds of it per ton of ore is required, as compared with coal tar, which costs only about 5c. per gal. Later, other coal-tar products less expensive than cresol came into use, and finally coal tar itself aided

* "Use of Coal Tar in Flotation," William A. Mueller, *Eng. and Min. Journal*, Oct. 9, 1915.

by some frothing agent, such as pine oil. Pine oil, however, is also quite expensive, and subsequent experiments show that coal tar with from 10 to 24% creosote gave equally good results. Until these experiments had been performed, coal tar was not considered as a flotation agent in this country, nor was it ever experimented with here, although it had been mentioned in some English patents. The experiments referred to led to its adoption in one large mill, and many others are now experimenting with it and getting good results.

There is considerable difference in the behavior of different tars, and it might be said that while classed as coal tar, the usual run of this material is really gas tar, or tar resulting from the manufacture of gas from coal. These oils are byproducts and naturally can be bought cheaply. A number of experiments have been carried out using this oil as a basis on ore of a porphyritic nature carrying about 1.6% copper, mostly chalcocite, with some chalcopyrite and about 0.15% oxide. Coal tar does not froth very well, producing a lean froth, although one of good quality. Pine oil is employed in combination with the coal tar, the pine product being a good frother and the combination of the two producing a carrying froth that gives good results in concentration. A mixture of 80% coal tar and 20% pine oil produces first-class concentrates. The price of pine oil, however, is high, and its use should be avoided whenever possible. The coal-tar products—cresol, creosote, etc.—which formerly served alone, are now mixed with the coal tar in proportions up to about 20%. The mixture thus obtained is excellent in both the pneumatic and agitation types of machines.

Use of Coal Tar with Frothing Oil.—When coal tar is used long enough, it alone gives low-grade tailings together with high-grade concentrates. It requires, however, that the ore be held in agitation such an inordinately long time that the practice is not considered satisfactory, and it is usually better to add some frothing oil along with it to produce the results in a shorter time. Some tars may not give any results at all when used alone, but as soon as a very little of such an oil as pine oil is added, good results are often obtained immediately. The amount of oil will vary according to the ore, grade of concentrates, and tailings desired; 0.005% of it will work a marvelous change in its effect upon some ores.

As the amount of tar increases in proportion to pine oil, the amount of concentrates increases and the mineral content of the tailings decreases. This may be on account of the proportion that coal tar bears to the mixture, or it may be because of the amount of oil resulting from increasing the amount of coal tar. Rough experiments seem to indicate that it depends upon the amount of mixture employed.

In a description of flotation tests on ores from Bisbee and Cobalt, Herbert J. French makes some interesting observations on oils.* In experiments on Bisbee ores the character of the material is described as porphyritic, the copper existing almost wholly as cupriferous pyrite, chalcocite, and malachite. The total copper amounted to 6.04%. After testing the ore in the slide machine, the tailings were analyzed for sulphur, whence the percentage of extraction of the sulphides could be computed.

Tests on Various Kinds of Oils.—Several oils, such as fish, sperm, whale, corn, cylinder, pine, pine-tar, lard, and cottonseed oils, were tried under fixed conditions. Both qualitative tests, by shaking oil, acid, ore, and water in test tubes, and quantitative tests on the slide machine were made. Of those oils available it was found that pine-tar oil gave the maximum extraction with the minimum weight of froth. Pine oil and fish oil both gave good results, but the froth, in addition to being of non-selective character, did not seem so lasting with either of these as that given by pine-tar oil. The character of the froth obtained by the other oils mentioned did not seem to indicate successful operation; hence the pine-tar oil was selected as the most desirable. In the experiment carried out at room-temperature on 100 grams of ore, the pulp containing sulphuric acid, with a 3-min. period of agitation, it was found that the extraction increased with the weight of oil added. A certain point, however, is reached beyond which more oil does not increase the extraction sufficiently to warrant its use in larger amounts. It is also evident that with the increase of oil, other conditions being the same, more of the gangue floats. In other words, the action of the oil becomes non-selective with increase above a certain point.

In another experiment, varying the acid, it was again found that there is a point beyond which further addition of acid is

* *Colorado School of Mines Quarterly*, November, 1914.

useless. When time is taken as a factor for variation, it is found that the longer agitation is continued the better the results. And again, when the temperature is the factor to be varied, it is found that from 50° to 65° C. gave as good extraction as could be had.

Experiments were then made upon ores from the Coniagas Mining Co., Cobalt, Ont. This ore contains about 13 oz. of silver per ton, mainly in the form of pyrargyrite, proustite, argentite, dyscrasite, and native silver. The procedure was about the same as for the Bisbee ore, but in this case the tailings were analyzed for silver. In the first test, which was made with different kinds of oil, pine-tar, fish, sperm, corn, whale, cylinder, rape-seed, lard, and cottonseed oils were tried, and it was clearly demonstrated that pine-tar oil was far superior to the others. Rape-seed oil gave a comparatively good extraction, but it was noticed that the froth was not so lasting as that produced by the pine-tar oil. The amount of oil was next varied, and in this case there was a recurrence of the phenomena of critical quantity. It was shown that beyond 2½ grams per 100 grams of ore, no benefits were derived from additional oil.

Examples of the Use of Mixed Oils.—At the Gold King mine, at Gladstone, San Juan County, Colo.,* a low grade silver-lead ore is treated by flotation, the oils used being carbolic and creosote. Carbolic oil is fed to the pump used to hoist the pulp to the stock tank, while creosote oil is fed to the first compartment of the agitator and pine oil is fed to the fourth compartment of the agitator, 300 c.c. of total oil per ton of pulp being used. In this case no acid is found necessary.

At a flotation mill in Mexico,† the best flotation agents among those tested were pine oils, a low-grade giving as good results as the better varieties. For the best work in flotation it was necessary to have pine oil present to the extent of 0.6 lb. per ton of ore. In actual plant practice, where the water is returned again and again to the top of the mill, the consumption of oil would reach about ¼ lb. per ton of ore. Pine-tar oil is much cheaper. It gives good extraction, but the grade of concentrate is low. Cresylic acid, when used with pine oils, increases the extraction about ¼ oz. of silver per ton. This hardly pays for its use. It

* *Eng. and Min. Journal*, Oct. 16, 1915.

† "Flotation in a Mexican Mill," *Min. and Sci. Press*, July 24, 1915.

may be said in connection with cresylic acid, however, that aside from any function it may have in assisting the actual formation of froth, it has the property of reducing the adhesion between oils that would ordinarily be wetted by water, and the water itself. Therefore the function of cresylic acid in the flotation process would seem to be in its quality of robbing water of the ability to wet certain oils.

It may be noted that so far in the review of the oils used coal tars have proved themselves to be poor frothers, and to get a sufficient volume of froth to make good recovery it is necessary to add something else as a frothing agent. Pine-tar oil, pine oil, creosote, etc., are the ones usually required. At the Inspiration mill, in Arizona, the flotation mixture is 80% crude coal tar, 15% light oil or creosote, and 5% pine oil. At the Daly-Judge, a mixture containing 40% crude coal tar, 40% creosote, and 20% pine oil is used. In the Coeur d'Alene country, wood creosote is used on zinc ores, and on some copper ores plain turpentine will work, but pine oil is better. The latter seems to have the property of making a brittle froth that does not seem to last long on reaching the surface of the floating machine, an advantage in many cases. Creosote and light oil makes an elastic envelope that will expand to great size before bursting. The pine-oil bubbles will rarely be over ¼ to ½ in. in diameter. Castor oil, olive oil, oleic acid, palm oil, sperm oil, and other oils of a lubricating nature have in general been replaced by oils more or less soluble or miscible in water, such as turpentine, pine oil, eucalpytus oil, and all other coal- and wood-tar distillations. Extremely volatile oils, such as naphtha, gasoline, ether, and alcohol, do not, apparently, have any effect themselves aside from the property they have of dissolving oils and thus making them more soluble or miscible in water.

On some of the mixed lead-zinc ores of the Coeur d'Alene country a mixture of three parts pine oil and one part creosote seems to work very well. The quantity used is about 0.5 to 0.7 lb. per ton. At the Silver Peak mill, Yerranderie, N. S. W., Australia, the best flotation results were obtained by the use of two oils. *Eucalyptus amygdalina* was used as a frothing agent and a dark lubricating-oil mixture as a carrier.* The pulp was heated to 120° F., at which best results were secured. The consump-

* H. Hardy Smith, *Eng. and Min. Journal*, Dec. 11, 1915.

tion of eucalyptus oil was ¾ to 1½ lb. per ton, and of the mineral-oil mixture 2 to 2½ lb. per ton.

The Qualities of Pine Oils.—In discussing flotation oils up to this point it will be noticed that there have been references to products from pine distillation, sometimes called pine oils and sometimes referred to as pine-tar oils. It might be assumed at first hand that this was simply two different ways of speaking of the same thing, but such is not the case, because the products are different. Pine oil is produced by the steam treatment of pine wood, cut up into small pieces, while pine-tar oil is obtained through the destructive dry-heat treatment of the wood. According to the specifications of the United States Navy Department, pine oil is defined as "a properly prepared light, straw-colored oil, produced by redistillation of heavy, high-boiling-point fractions, resulting from the steam distillation of wood turpentine, and having a strong aromatic odor resembling turpentine." This oil should have a specific gravity of not less than 0.930 or more than 0.945 at 60° F., and upon distillation should show at least 75% distilling between 200° and 220° C. The same authority, defining pine-tar oil, says: "A properly prepared distillate from straight pine tar, which latter has been obtained by destructive distillation of pine wood." It will be clear, then, that the two products are different and are not necessarily interchangeable in use where experiments have been made upon only one.

Only a small amount of pine oil is produced, not nearly sufficient to supply mining demands. High-grade pine oil is also used for medicinal purposes and, pure, commands from 60 to 80c. per gallon.

Long-leaf pine produces a number of oils, just as petroleum gives a variety of products. The fact that pine oil, which has a short range of distillation and is heavier than turpentine, was on the market and was used in flotation mixtures has led to the belief that no other oil coming from the pine tree would serve the purpose as well. Experiments, however, prove that oils heavier than pine oil, when properly mixed with other oils, produce a better froth than pine oil. By the usual methods the distillation of pine oil is not carried beyond a specific gravity of 0.940. Stills are not equipped to carry it higher. Medicinal practice demands an oil distilling between 190° and 220° C. Ex-

periments show that the oils distilling above 220° C. are the best for flotation.

Oils are now produced of a specific gravity beyond 0.970, but they are too thick to handle easily, and are mixed with lighter oils, resulting in two grades, 0.875 and 0.900 specific gravity. They produce a splendid froth.

Some tests have been made on pine oils, in one of which the oil was noted as orange in color and having a specific gravity of 0.945. In this experiment 2 lb. of the oil was used per ton, and 2 lb. of acid was added to the pulp and agitated one minute before the oil was added. It was found that by using the oil thus, a good product was obtained, but by making two or more operations on the same pulp, adding 1 lb. of the pine oil first and then at the second operation a pound of oleic acid, a high-grade product was also produced. In testing two or three kinds of pine oil in combination with oleic and other oils, it was found that a consistently good product was obtained each time, and that the percentage of extraction increased with the number of operations that were performed on the pulp, up to the point where practically all the sulphide had been removed from the oil.

In describing the flotation process at the Oneida Stag mill, at Idaho Springs, Colo., R. W. Smith * points out that oil at the rate of 2½ lb. per ton of dry feed was added. The oil cost was materially reduced by mixing three different kinds—in this case consisting of one part of mixed crude wood tar, fairly cheap; one part of spirits of turpentine, more expensive; and four parts of a cheap, local mineral oil. The mineral oils constitute a cheap base for carrying the other oils. It is not always possible to find a mixture that will give a clean, high recovery and at the same time make clean products. By mixing in this way, however, the cost per gallon for oil on the ground was reduced from 45c. to 23c. This reduces the cost of oil per ton of crude mill feed from 6c. to 3c.

Oils Used at the Anaconda Mill.—In the description of flotation at Anaconda, the kind of oil used for their flotation has been noted by Laist and Wiggin.† A product that has heretofore been little used in flotation, but has been the subject of some experimentation, is a kerosene sludge-acid that has been employed

* "Flotation Replaces Cyanide," *Eng. and Min. Journal*, Jan. 15, 1916.

† *Bulletin A. I. M. E.*, March, 1916.

by Minerals Separation and is called M.S. 37. It was used practically all through the experimental work at Anaconda and gave highly satisfactory results. Although exposed to the weather in iron drums during the winter months, it gave no trouble by becoming too viscous. One barrel of oil from the Western Oil Co. was tested during February, but did not give as satisfactory results as the oils from Standard Oil Co. and the Union Oil Co. of San Francisco. One barrel of oil from the Midwest Refining Co. was tested during February, but did not give the results obtained on the other two. From the Producers Refining Co. came an oil that could not be tested, as it had solidified in the barrels and did not become liquid after standing for days at a temperature of 60° F. or better.

During the experimental work creosote oils were tested with varying results. The creosote from the Cleveland Cliffs Iron Co., of Marquette, Mich., is obtained as a byproduct in the manufacture of charcoal from hard pine. This is known as M.S. No. 33, the number given to it by the Minerals Separation Co. It was used practically throughout the entire work with highly satisfactory results. Creosote from Pensacola Tar and Turpentine Co., of Gull Point, Fla., was used in considerable quantity in experimental work. It gave fully as good results as the Cleveland Cliffs creosote. It is made from Georgia pine and is known as No. 400 by the Pensacola company. A barrel of creosote from the Crichton Pine Products Co., of Alabama, was tested and gave good results. A test was made using a barrel of tar creosote from the Butte Gas Works, and this gave fairly good results. The test was too short to be conclusive, but it was thought that the tar creosote would give satisfactory results.

In testing the Callow machines a mixture of oil containing tar creosote from the Barrett Manufacturing Co. was used with good results. In the laboratory experiments it was found that tar creosote gives good results. Creosote from the timber-treating plants at Rocker comes from the J. F. Lewis Co., of Moline, Ill. It did not give good results, although the test was too short to be absolutely conclusive.

The Acid-Hydrocarbon Products.—The reference to the kerosene sludge acid introduces a new oil, or hydrocarbon product, that has not been spoken of before, the manufacture and production of which is not well known by flotation men. The product

is one from the distillation of petroleum. The burning-oil stocks from the steam stills, consisting of from 65 to 75% of the crude oil charged, are treated at the rate of 5 to 10 lb. of 66° commercial sulphuric acid per bbl., in order to improve the color and odor and also to remove decomposition products which cause the flame to smoke when burned in lamps. The process is performed in agitators, using an air-blast for agitation. In order to get the full benefit of the acid, any water present must first be drawn off and a small amount of acid added in order to remove all the remaining water. This is agitated for from 20 to 40 min., allowed to settle from the oil and then drawn off. The remaining acid is then added and the mass agitated for from one-half to one hour, allowed to settle from 3 to 5 hr., and drawn off. The acid treatment removes the tarry matter formed during distillation, also a large percentage of the unsaturated hydrocarbons and sulphur compound. The acid is turned almost black after treatment, and is known as sludge acid. It is allowed to settle from the oil and is then drawn off into tanks and delivered to the acid-separating plant for the recovery of the acid. This sludge acid is the product that has been found useful in flotation. It will be observed that it comes from the treatment of light burning oils. A similar process is practiced upon the lubricating oils, but the sludge acid from these heavier oils is black, asphaltic in nature, and very viscous—almost a solid mass. It, with the sludge from the burning oils, is sometimes agitated with water in a lead-lined separator, the weak acid recovered is concentrated in lead pans, and finally in stills of cast iron to 66° Baumé, and then used over again. The residue from this treatment is usually used for fuel or worked up into pitch. It will be seen that the use of these sludge-acid oils may possibly combine the features of having the oils necessary for reducing surface tension together with the acid required in the treatment of some particular ores.

In a test made on some oleic and coal-tar oils, a cycle of four different operations was carried out on each. The test was performed at a dilution of 4:1 and at a temperature of 45° C., the ore being a typical blende combination with heads averaging 15½% Zn. The additions consisted of the oleic oil and 2 lb. of acid per ton. Clean concentrates of 45.6% zinc were produced, with clean tailings containing 1.3% zinc. In using the straight

coal-tar oil the same feed produced clean concentrates of 49.5% and clean tailings of 1.2% zinc. In each case there were four operations performed.

Pine Oils and Petroleum Products.—There are several different kinds of pine oils, made by different manufacturers, and although the qualities are in general approximately the same, some difference may be found in particular products. Taking for example Spiritine and the Atlantic as two different examples of pine oils, it has been found that they both give good froth. It may be noted that when pine-tar oil is used, a long contact with an acid solution will be likely to cause the froth to break up and the concentrates to drop out of it. For this reason, where long contact is essential it is believed, at least in some cases, better to take an oil in which the pine-tar product does not exist. One of the two pine oils has been found to contain pine tar, and although it gives an excellent froth on short agitation, long contact with acid will, as has been said, cause the concentrates to drop out of the froth. Where acid is not used, however, pine-tar oils are particularly advantageous and make splendid froths. A large number of tests have been made with acid petroleum products, some of which make good flotation oils. In tests on Texas crude oils, most of them have been found to give good results in combination with a frothing oil. The frothing oils used in combination in this case were oleic, stearic, pine, and pine-tar oils. The Texas crudes are usually known as A, B, C, D, E, and F. Combinations containing half of these Texas oils and half of one of those that have been mentioned as frothing agents were tried, and most of them gave very good results. The Texas crude "A," in proportion of one-half to one-half of stearic, however, requires considerable agitation. This agitation is more than is required when the other combinations of oils are used. The combination of the Texas crude "C" with oleic acid, in the proportion of half and half, froths pretty well, but the froth did not show much strength nor stand up well.

The Minerals Separation oils have already been referred to, but in some cases they are used in combination with pine and pine-tar oils, as well as with oleic and stearic acids. In a few cases, however, tests of a mixture with oleic and stearic acids did not give good results, but there was probably some local reason for such an outcome.

Thorough tests have also been made of such products as crude oil, fish oil, and many others. Fish oil gives good results, and a combination of fish oil and oleic acid does too, although it shows some tendency to carry up siliceous matter with the mineral. Fish oil and pine oil in combination do not seem to do any good at all. In the experiments made on this combination, no results were secured. Stearic and oleic acids give good results, as also does stearic acid alone. Beaumont oil with tar oil and with oleic gives fairly good results, and some paint oils may also be successfully used. Coal-tar oils have already been mentioned, as has also their combination with pine oil and other frothing agents.

Tests on More Unusual Oils.—Pine oils and pine-tar oils have been tried in combination with cottonseed, lard, nitrobenzol, turpentine, oleic acid, stearic acid, corn oil and other hydrocarbons. The results seem to vary with the kind of ores treated. In many cases a good result can be obtained with blende ores, while the same oil combination will not work at all on copper. At the same time, if the oil mixture is changed and also its proportion to the dry ore itself, the same oils, alone and in combination, may be made to do good work on the copper ores. The same applies to the treatment of any other kind of ore where changes in oils seem to give different results. In spite of the efforts that have been made to discover some rule for the application of various oils to different kinds of ores and in spite of the careful study given to the matter, no general principles can be announced. At many times the experimenters have seemed to be on the track of a logical explanation, but with the formulation of rules, numerous variations and objections to it have cropped up, so that at the present time there is really nothing that can be laid down as specific.

Tests have been made on corn oils, and the corn oil in combination with pine, pine-tar, oleic and stearic acids has been tried. All of them give good results under some circumstances and poor results under others. It might be said in general that any oil will form a good flotation product if the proper combination with its complementary oil is used. By this is meant that if a carrying oil is used, it must be supplemented by a small quantity of a frothing oil. The frothing oils and the carrying oils are complementary to each other, one supplying the qualities that the other does not possess. There are some oils that combine

the qualities of carrying and frothing agents, but as a rule they are so expensive that they cannot be used alone, and it is found cheaper to use a large quantity, comparatively speaking, of the cheaper carrying oil and a much smaller quantity of the more expensive frothing agents. Of the Texas crude oils there seems to be none so far tested that can be depended upon to give satisfactory results alone. They all have an asphalt base and bring forth a light, rich, unstable froth. In combination with either pine, oleic, or pine-tar oils they give good results. They are graded according to their specific gravity, the lightest oil being the Texas "A" and the heaviest the Texas "F." The latter, in combination with oleic and pine in a proportion of one-third each, gave remarkable results on some careful experiments.

Comparison of many different kinds of pine oils show that there is very little difference in the product of different manufacturers, most of them having about the same properties. Oleic oils have been tested in combination with corn, pine-tar, turpentine, and other oils, and also straight. In proper quantities they seem to give good results in every case. Oleic oils of different manufacturers have been also compared, and there seems to be very little choice between them.

Miscellaneous Oils Tested.—Tests on a lot of miscellaneous oils have given, in general, good results, although some will not work when economically possible quantities are used. Wood creosote works well and produces a good, thick froth, but has a tendency to carry silica into the froth. Spike oil was tried, but it usually does not seem to produce a froth that is tough enough for practical satisfaction. Rape oil produces a pretty good froth, fairly clean, although on continuous subsequent operations there appears to be a peculiar scum that interferes with satisfactory flotation. Nitrobenzol is too light for flotation, and no results can be had with it. Castor oil alone does not usually produce good results. In combination with turpentine it will work satisfactorily, but such large quantities of it have to be used (up to 8 or 10 lb. per ton) that it is not economically practicable. Cottonseed oil and coal oil (kerosene) alone did not produce any practical results. Coal oil and pine-tar produce pretty good results, but require a large quantity of the oil in proportion to the tonnage treated. Turpentine alone does not produce satisfactory results, according to experiments, nor does

the variation called turpentine oil. All the turpentines work fairly well, however, when combined with a heavy oil. The use of fish oil in large quantities gives fairly good results, but its extremely disagreeable odor would be a drawback. The trouble experienced when stearic acid is used alone seems to be that stearic brings the congealing point down, and this oil also takes more heat to render it liquid enough for use. It seems probable that coal-tar oils and coal tars themselves will probably be the most generally useful oils in flotation processes, being used as carrying oils and forming the bulk of the oils added. They must, however, be combined with some oil having frothing qualities, such as pine, pine-tar, or many of the other lighter oils already mentioned.

The practical result of a large number of oils tested seems to be that the only way to determine whether an oil is applicable for flotation of a certain kind of ore is to try it on that ore. And, it will be noted, it is advisable to try an increasing number of oil combinations and quantities. Since, as has been mentioned, it is totally impossible to outline any rule for forecasting the results to be given by oils of certain classes on ores of particular kinds, a large number of experiments is absolutely necessary to accurately determine such oil or combination of oils that can be used, and the minimum quantity that can be used to secure the greatest economical quantity of flotation concentrates.

Testing Flotation Oils.—Oils may be tested for their use in flotation plants and, in fact, no oil should be used until a thorough test has been made and its value for use in the plant proved. The great difficulty is that there is no standard way of making tests that will indicate the usefulness of an oil in flotation, so that the usual method is to choose a standard ore on which tests of all kinds are run and recorded, the effect of the oils being referred to this particular ore as a standard. This method has been brought out by J. Coutts.* He points out that the first thing to do with an oil is to measure its density for future calculation, as it will be measured by volume in the laboratory and there must be some method of transferring these volume units into weights.

Coutts classifies three different kinds of standard tests: First,

* "Aust. Min. Standard," Apr. 8, 1913. Reprinted in *Eng. and Min. Journal*, June 19, 1915.

one for mixed sulphides; second, one for differential separation; and third, one for the flotation of copper and iron sulphides. He believes that oils high in phellandrene are best for differential separation of zinc-lead-sulphide ores. Phellandrene is an oily constituent that leaves a gummy residue on evaporation. It may be tested for by evaporating oils at moderate temperature and examining the residue, or it may be detected by the polariscope. An oil giving a deflection by the polariscope of 60 or over is considered to have a sufficient quantity of phellandrene for use in copper flotation.

For testing the number of drops of oil in each cubic centimeter a small burette is recommended, the discharge orifice of which has been made smaller by heating and dumping it up. About 80 or 90 drops per cubic centimeter should be given at normal temperatures. The number of pounds of oil per ton of ore can be found, when the specific gravity and number of drops in one cubic centimeter are known, from the accompanying formula:

$$\frac{2{,}240 \times sp.gr.}{453.6 \times drops\ per\ c.c.} = lb.\ of\ oil\ per\ ton$$

The great difficulty in testing oils for flotation is that it is not yet known what quality it is that makes oils of value for flotation. The only way to find out if an oil will do for this purpose is to try it on the ore to be tested. Some laboratories have under way series of tests looking toward the determination of the flotation quality of oils, and also the matter of changing the quality so that they may be used for flotation successfully. In this case reference is not had to the mere mixing of oils to secure good flotation froth, but the actual changing of the quality of the oil itself by such means as dissolving different materials in it, sulphonating it, or modifying it by heat or other treatment. Some progress is being made on the production of oils of good quality from cheap oils that can be obtained readily in particular localities.

The Classification of Oils.—The New York Produce Exchange defines crude petroleum as follows: "Crude petroleum shall be understood to be a pure, natural oil, neither steamed nor treated, free from water, sediment or other adulteration, of the gravity of 43° to 48° Bé."

Since the production of the lower Baumé gravity oils, the limitations in regard to gravity have been relaxed. In order to ascertain whether or not the petroleum conforms to the foregoing rule, it is usually distilled in 10% fractions, and the Baumé gravity determined on each fraction. It is obvious that from the complexity of crude petroleum each succeeding fraction would show a somewhat regular graduation in specific gravity, whereas in cases of adulteration it would be more or less irregular. There are a number of tests that can be performed on oil to determine its constituents in oils of different gravities and also to determine the quantity of sulphur contained, the specific gravity of the oil, the water contained, and other tests. Burning oils are usually tested to show their flashing point. Lubricating oils are also tested in the same way to show their flashpoint, and in addition, their viscosity and their cold test—that is, the temperature at which they become solid. All of these are set forth in detail in the textbooks on the subject of oils and are too complicated to be treated here, particularly in view of the fact that they have no relation whatever to flotation so far as we know at the present time.

Aside from the petroleums there are many liquid fats and fatty oils in addition to the solid fats. In the first class there are the vegetable oils, which may be divided into drying, semi-drying and non-drying. In the second class are the animal oils, which are subdivided into marine animal oils, such as fish oils, liver oils, and blubber oils; and the terrestrial animal oils.

The solid fats are divided into vegetable fats and animal fats, and the latter are subdivided into drying fats and non-drying fats. In these classes come a host of different kinds of oils, many of which have already been mentioned in this article and hundreds of which have not. It seems that almost every vegetable or plant will produce an oil having some different qualities from every other. There are also animal oils and fats of different qualities and having different effects. Only a few of the large number are of interest in flotation, because only those few occur in such abundance as to be commercially cheap enough to be used in a commercial process of this kind.

Froths and Their Character.—The kinds of froths formed by the different oils used in flotation have been described by W. A.

Mueller,* who has also considered the effects of different machines and conditions on froths. He points out that for studying the various froth characteristics of an oil a small testing machine works well and is handy to use. The froth produced by various oils differs with the machine in which it is made. In the Minerals Separation type, where the froth rides in the spitzkasten for some time before leaving it, there is plenty of time to collect, and the froth always lies in a "dead" state, only coming off as it is forced out by new froth from the rear. In this case the froth loses its characteristics so far as the bubble itself is concerned. In the Callow type of machine the froth is always in rapid motion and no dead froth accumulates. It is kept overflowing by the constantly rising bubble column formed. In the Cole-Bergmann and Flynn-Towne types of machines the froth acts in the same way. In these two, however, a deeper froth column is carried and this makes the bubbles slightly smaller. In the Hebbard type of Minerals Separation machine the froth is in more rapid motion than in the regular machine, owing to there being no settling compartment and also because of the introduction of air. There is no accumulation of dead froth except at times around the shaft of the agitators.

In adding oils for flotation it is of the utmost importance that they be well mixed with the pulp before flotation is attempted. If not thoroughly mixed, the oils kill froth rather than produce any. When a machine is in good working order and some raw oil suddenly gets into the pulp, the froth immediately seems to dissolve, leaving the pulp showing through the froth. In these cases the froth rushes back and forth in the machine, the bubbles become very brittle and finally disappear.

The practice of using a shallow froth is considered good by some metallurgists, but does not really aid except where there may be a temporary air shortage in the air type of machine. The usual depth of froth in the Callow type of machine is about 15 in.; in the Cole-Bergmann and Flynn-Towne machines it is from 24 to 36 in., while in the Minerals Separation type the froth level varies from 6 to 12 in. in the spitzkasten, and in the Hebbard type it runs from 6 to 10 in. The raw-oil condition in a machine can readily be distinguished from the high level of pulp

* "Froths Formed by Flotation Oils," *Eng. and Min. Journal*, July 1, 1916.

condition by the depth of pulp from the top of the machine at the time the condition is noticed. The raw-oil action is detrimental to flotation and should be avoided. Cup greases and lubricating oils give the most trouble of this kind in plants.

The froth characteristics described apply to live froths such as are formed in the air types of machines. The agitator type, with the exception of the agitator-and-air type combined, usually has a spitzkasten or settling compartment in which the froth congeals and so loses its bubble characteristics. In these machines the froth characteristics are not so noticeable.

Characteristics of Pine-Oil Froth.—There are several grades of pine oil, but the various kinds have practically the same effect on the froth. Pine oil is rather soluble, and it is this characteristic that is largely in its favor, as its presence, once used, is always detected in the mill water as long as the tailings and concentrates are dewatered and the water reused. After using pine oil a short time, only a little of it need be added—just enough to make up for any small amount that may have been lost or carried away by the concentrates after dewatering.

The pine-oil froth is brittle and the bubble produced is small, the largest one being only about ¼ in. in diameter. A small amount of oil produces a large quantity of fine-grained froth. The bubble film is very delicate and, on rising to the surface, breaks immediately. Its burden of mineral, if there is any, is deposited on the bubble immediately following, and thus the mineral is carried along on the surface until it flows over a lip or otherwise is removed. Pine oil as a general rule is a rather poor mineral oiler, but a good frothing agent. For this reason it is used principally as a frother, although there are some cases where it will take the place of a mineral oiler as well as the frothing agent. Its action is delicate, and at plants where pine oil is largely used, the machines will require much closer attention. It is a good mineral collector for ores carrying chalcocite and on some zinc ores. A pine-oil froth, in addition to being brittle, is also watery and at times, when there is too much of it present, it tends to make a dirty froth and low-grade concentrate. When present in these large amounts, the concentrate froth will often carry large particles of silica and gangue material. The froth, however, does not toughen up because of its excess oiling, and in this way pine oil differs from most others.

The froth will be dirty, as is the case with other oils, and cannot be cleaned, but the latter is due largely to excess froth rather than to the toughness of the froth. By the addition of acid, or sometimes a caustic, its action as a mineral collector can often be increased, but it still retains the same characteristics of brittleness and delicacy.

Next to the pine oil the most important flotation agent is perhaps coal tar. The action of this has already been described, and it has been shown to be a poor frothing agent but a good oiler. It is seldom used alone. When it appears as a foreign oil in the machine it lacks the strong froth-killing power of the other oils, but lies on the froth in flakes, sometimes deadening the froth in the immediate vicinity and at other times seeming to mat the small bubbles together, forming a sort of hole in the froth toward which the bubbles in the vicinity have a strong tendency to rush. Arriving, they seem to be swallowed up much as a cork will act when thrown into a whirlpool. Raw coal tar in the machine is not so detrimental as the other oils, but it should be avoided. When in great excess coal tar has a strong tendency to separate, as has been noted, even when apparently well mixed. Even though it has no strong frothing power, when too much is used it will cause some excess frothing and a dirty froth, though not so easily as other oils.

The Action of Coal-Tar Creosote.—Coal-tar creosote is used mostly as a dilutant for the cheaper coal-tar oil and for this purpose it is very good. The bubble has a tendency to be rather large, ranging in size from about an inch in diameter to as much as 12 in. and sometimes even more. It is very tough and in breaking, the bubbles tend to expand rather than be destroyed altogether. With two bubbles side by side, the breaking seems to take place in the film uniting them, so that where there were two bubbles at first, there is only one after bursting. This enlarging of the bubble, of course, has its limit, and we seldom see them much over 12 in. in diameter unless there is a great excess of creosote, when they may get to be of such size as to reach across the machine. On bursting, the mineral burden is delivered to the film of the neighboring bubbles with which they were in contact before bursting. The bubble has good carrying capacity for mineral. When too much oil is present, however, there is the same tendency to carry gangue, and this is usually at the ex-

pense of the mineral. The oil mixes rather easily, the action in the Pachuca tank being sufficient, although mixing in the grinding mills is at all times to be recommended.

Wood-Creosote Bubbles.—Wood creosote has some of the same characteristics of the coal-tar creosote, but differs widely in others. The toughness of its bubble is even more marked. The size of the bubble is different and the two oils are not interchangeable—that is, one cannot be used as a substitute for the other, as coal-tar creosote seems to work better on copper-bearing ores than the wood creosote and the latter seems to work better on zinc ores. Wood creosote is often used as dilutant for coal tar in the flotation of zinc ores. The size of the bubbles varies greatly. The characteristic froth shows small ones resembling the pine-oil bubble, together with the larger ones. There will be a large one about 3 in. diameter as a maximum; then there will be a group of smaller ones, ranging in size up to maybe ½ in. diameter, which separate the larger ones from each other. The froth, like that of coal-tar creosote, is tough, and a small excess of oil makes a dirty and voluminous froth that is hard to break up. The bubble varies from this type when an excess of oil is used, tending to become larger and more elastic.

Turpentine is not used so much at the present time as when flotation first appeared in this country. The turpentine froth is persistent and elastic. It has a tendency to hold everything that comes in contact with it, and for this reason it was formerly used to bring up the middlings and was added after the concentrates were taken off. For this purpose it was good, but the froth is so tough that it is hard to break down, so that cleaning it is difficult. Usually the middling produced by means of the turpentine could not be cleaned to any appreciable extent. The turpentine bubble ranges in size from ½ in. to 2 or 3 in. diameter. It is elastic, and the volume of froth produced is always excessive and, as a rule, low-grade. For this reason it is not used much at present.

Cresol, or cresylic acid, was formerly the chief frothing agent used in the flotation of copper minerals, but its use is now limited to small proportions in the mixtures with coal tar. The cresol bubble is of medium size—that is, from ½ to 2 and 3 in. diameter—and as a rule the bubble is not too brittle and not too tough, but made a good froth to handle. The nature of the oil, how-

ever, made it disagreeable to handle and also somewhat dangerous; this, together with the bringing out of coal tar and the advance in price of cresol, gradually brought it to a point where only a comparatively small amount is now used.

The oil was a good frothing agent as well as a good mineral collector, and its use was formerly almost universal. The froth is rather easy to break down, and the concentrate produced is easily cleaned. The oil is very slightly soluble in water and mixes rather easily. Violent agitation, as in a Pachuca tank or in the Minerals Separation type of machine, is often enough to give good distribution and a good flotation froth.

The froth produced by fuel oil is of the same appearance as that of coal-tar creosote as far as the bubbles are concerned, which are nearly the same size, ranging from 2 in. to 4 and 6 in. diameter. The froth, however, is very brittle when the right amount of oil is used and is much cleaner than the creosote. In fact, the froth is almost too clean, so that a clean tailing is hard to make with fuel oil alone. Mixed with some oil like creosote, however, it sometimes does good work. The concentrates from the preliminary treatment often need no further treatment. Where a final product is made as concentrate the tailings are usually re-treated, and in such cases the creosote effects seem to carry through to the other treatment, while the fuel oil often has to be added in the second treatment. Various ores differ slightly on this point. Again, a little fuel oil in a coal tar-creosote mixture will sometimes aid in cleaning the froth.

When fuel oil is in excess, the froth produced is stringy and the bubbles often get to be of such size as to stretch across the machine. I have seen them over 2 ft. in length. The froth under these conditions is also dirty and will pass through a cleaner without improving the grade of concentrate. Acid is sometimes an aid in the use of fuel oil, especially when the oil is in excess. The froth from excess fuel oil is hard to break down.

Pine-tar oil is coming into use more now as a possible flotation agent for copper carbonates, but has disadvantages. It is stiff and flows poorly, so that it must be mixed with some other oils in order to make it of such viscosity as to flow. The froth resembles that from wood creosote and pine oil in appearance of the bubbles, but in texture it is much more fine-grained than the wood creosote. It is a powerful frothing agent similar to

pine oil. It is easy to flood the plant with froth from this oil. The froth is characterized by being dirty, but, like pine oil, is capable of holding up considerable coarse mineral as well as gangue. When a flood of this froth reaches the cleaner, it is subjected to very little cleaning owing to its frothing character. Often the addition of a small amount of fuel oil will tend to make a cleaner froth, but with the pine-tar oil a very clean froth must not be expected except at the cost of high tailings.

Oleic acid is used at several plants in this country and is confined mostly to zinc ores. It produces large bubbles and a tough froth. The size of the bubbles varies with the amount of oil used, but ranging from several inches to a foot in diameter. The froth is very persistent and stringy, and the bubble film is often strong enough to support light objects.

Introduction of Foreign Oils.—Under this head are also included greases, even though they are not literally oils. Under no circumstances should these oils or greases be permitted to come into the feed delivered to the flotation machines. A common place to find some of this trouble is around the bearings and gears of the pebble and ball mills; here an enormous lot of grease and oil is used and a great deal wasted. Dripping bearings give their share of trouble. If foreign oils get into the feed before entering the mills, it is then mixed and its effect is distributed over a large amount and does not give quite the trouble as when it finds its way in after leaving the mills. Sometimes acid will remedy the effect of foreign oils when they cannot be avoided in any other way, if their source is ahead of the grinding mills, but the effect of the acid on the flotation must also be considered. Usually the best thing to do is to find the source of oil and eliminate it. Froth from lubricating oils is tough and stringy and carries little mineral value and is almost uncleanable. The bubbles are hard to break down and, when once broken down, will form again at the slightest opportunity. A large amount of foreign oils come from cleaning up around the plant. The mineral content of tailings is not reduced by the action of these oils; they merely act as an annoying frothing agent that may bury the plant in froth.

As a general rule the best froth to be used is one in which the bubbles are of a medium size and rather tough, although too tough a bubble should be avoided. For chalcocite, pine oil works

best, but this froth is delicate and a froth of this kind needs constant attention, so that an operator cannot care for as many machines as he otherwise might. Coal-tar mixtures of from 50 to 80% coal tar and 50 to 20% creosote, with small amounts of pine oil added from time to time, will often give the same results and much steadier conditions than the pine oil on chalcocite ores. The best mixture would have to be worked out in the plant.

Chalcopyrite responds readily to the same mixture as chalcocite, but the pine-oil froth does not do very well with the chalcopyrite. Zinc and lead ores vary greatly. Some will respond beautifully to mixtures of coal tar and wood creosote and some with coal-tar creosote, while others will not respond with any oils but mixtures of wood-distillation products. Then there are still others that seem to require the addition of acid in order to do anything at all.

Further Experiments on Oils.—The question of the determination of the qualities of oils that makes them available for flotation is a serious one, but no way of finding those qualities and testing for them before using the oil has been brought forth. A tentative line of experimentation has been suggested by C. Y. Clayton and C. E. Peterson,* of the Missouri School of Mines and Metallurgy, who suggest the investigation of the following qualities: Dielectric strength; optical properties—the power to absorb certain rays; insulation value; viscosity; water-soluble content; facility of emulsification (mixing); surface tension; specific gravity and chemical composition.

Among the experiments suggested are those determining the relation, if there is any, between the selective power or frothing power of an oil and its dielectric constant, and its viscosity. Also to determine whether surface tension and film strength play any part in the frothing or selective power of an oil; whether saponification bears any relation to the flotation power of an oil, either as to its frothing or selective value. The facility of rapid subdivision and flotation value. The water-soluble content and its value to flotation. What the quantitative effect of frothing and selecting oils may be, and the possible relation between a mineral s dielectric constant and its tendency to be floated. The grouping of oils as to their chemical composition should be

* *Min. and Sci. Press*, Apr. 22, 1916.

worked out, ascribing flotative value to the groups and comparing the group members. The effect of salts of different kinds in different amounts on flotation oils should be considered, as should also the method of union of oils and bubbles. Many of these points have already been investigated, but others of them have not been, and any additional work would be a benefit to the operation of the process.

CHAPTER V

FLOTATION PROCESSES AND APPARATUS

The Elmore vacuum process, the invention of F. E. Elmore, is based primarily upon the fact that, in a flowing pulp of crushed ore and water, oil has a selective action for the metallic mineral particles as distinct from the rocky particles or gangue. This selective action is materially increased, in some cases, by the use of an acid. Secondly, dependence is upon the fact that the air or gas dissolved in water is liberated, partially or entirely, upon subjecting it to a pressure less than that of the surrounding atmosphere. The liberated gases may be augmented by the generation of gases in the pulp or by their introduction from an external source. The gases attach themselves to the greased mineral particles, and being largely increased in volume as a result of the partial vacuum applied, cause the greased particles with their attendant bubbles of air or gas to float to the surface of the liquid. The process has been extensively reviewed by Alexander Stanley Elmore,* from whose work this description is taken. The operation of the process is shown by reference to the accompanying drawing. The pulp containing crushed ore flows continually into the mixer *A*, into which also is introduced small quantities of oil and, if required, of acid also at the point *B*. The agitation is secured by rotation of the beater *C*. The agitated pulp flows continuously from the mixer into the funnel *D*. The concentrate-discharge pipe *E* and the tailing-discharge pipe *F* are both sealed with water in the tanks *G* and *H*, respectively.

The upper end of the feed pipe *D* enters the center of a conical separating vessel *I*. The rate of flow of the pulp down the pipe *F* being slightly less than the inflow of the feed pipe *D*, a small amount of liquid overflows the rim of the annular space *K*, this quantity of liquid being sufficient to carry the concentrate in the pine into the tank *G*. The rakes *L* are caused to

* *Eng. and Min. Journal*, May 11, 1907.

rotate slowly by means of the worm and wheel *M*, the angle of the blade being such as to cause the solid matter in the pulp to travel from the center to the outside of the conical chamber, whence the tailings continuously discharge down the pipe *F*. The feed pipe *D* is usually about 25 to 30 ft. long, the tailing and concentrate pipes *E* and *F* being a few feet longer, so that in effect the feed pipe and tailing pipe form the long and short

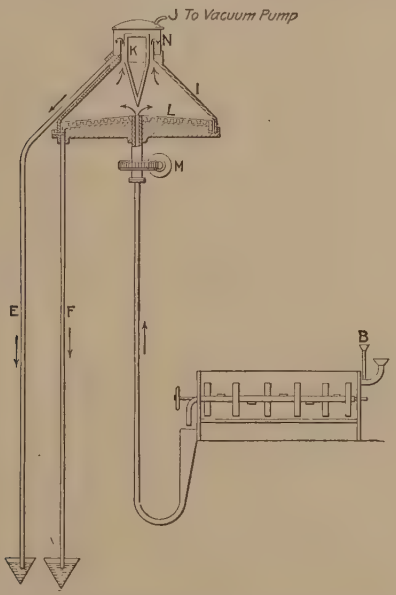


FIG. 4.—THE ELMORE VACUUM APPARATUS.

legs of a siphon; thus, the power required to elevate the pulp into the conical chamber is supplied by the falling of pulp in the tailing pipe. So long as a continuous flow of pulp is supplied to the mixer, a continuous and entirely automatic discharge of tailing and concentrate is secured. The annular space *K* is surrounded by a thick glass cylinder, or by a metal cylinder with one or more thick glass windows through which the discharge of concentrate over the edge of the annular ring may be observed.

The apparatus is constructed of metal with the exception of the glass windows, the mixer being a simple wooden trough with wooden beaters. The power required for a 5-ft. unit of such a plant does not exceed 2 to 2½ hp., including that required for driving the vacuum pump, mixer, and separator. The apparatus is usually constructed in standard units, the conical separating chamber of which is 5 ft. in diameter.

The capacity of the apparatus naturally varies with the kind of ore to be treated, the fineness to which the ore has to be ground, and some other conditions, but a 5-ft. machine will ordinarily treat from 35 to 45 tons of crude ore per 24 hr. The cost of the plant is low for so large a capacity. Extensive foundations are not required, because the beaters in the mixing cylinder only make from 30 to 40 r.p.m., and the rakes in the conical separating chamber only 1 or 2 r.p.m. Vibration is therefore entirely absent. No sizing of the pulp is required and the operation of the plant is entirely automatic.

The quantity of oil and acid required is not the same for all ores, but usually amounts to not more than a few pounds, say from 3 to 10 lb. per ton of ore treated. Probably the following figures will be of interest as giving a fair idea of working costs. Naturally, the price of acid, oil, and labor will vary at different mines: Oil, say 7 lb. per ton of ore treated at 1c, 7c; acid, where required, 6 lb. per ton at 1c, 6c; labor at $2.50 per 8 hr., 11c.; total 24c. This is on the basis of a plant of, say, 200 tons per 24 hr. capacity. To the above, the cost of, say, 0.05 hp. per ton has to be added, say 10 hp. for a 200-ton plant.

The Macquisten Tube Apparatus.—The Macquisten process has already been described in general, but it would be well to consider further its action in practical application. The process has not been widely applied, at any rate in the United States, but at least one important plant still exists—that of the Morning mill of the Federal Mining and Smelting Co., at Mullan, Ida. Another installation is at the Iron Mountain mill, in Montana, just over the border from Idaho.

The best description of the Macquisten process was given by W. R. Ingalls,* who described its installation at the Adelaide Reduction Works, of Golconda, Nev. This description is com-

* "Concentration Upside Down," *Eng. and Min. Journal*, Oct. 26, 1907.

plete and exceptionally clear, so that exhaustive quotations from it will be the best method of illustrating the practical working of the process.

The Adelaide Reduction Works was erected a number of years ago to reduce the ore of mines that had been acquired by a mining company in the vicinity of Golconda, chiefly at Adelaide, about 14 miles south of Golconda. The works comprise a concentrating mill and a small smeltery. The latter has two Bruckner roasting furnaces and three small reverberatory furnaces, rated at capacity for smelting about 30 tons of ore per day per furnace. The works were operated for a brief period, but were found unable to treat successfully the Adelaide ore, and consequently were closed, since when they have been run only when some new process was to be tried.

The Adelaide ore is chalcopyrite, with a smaller proportion of pyrrhotite and pyrite, and a little blende and galena. These minerals are rather finely disseminated in a hard, dense, quartzose gangue that also contains spinel and garnet. The presence of the heavy gangue minerals caused concentration by ordinary treating and tables to be ineffective. Wilfleys, vanners, and other forms of tables all failed. Then a trial was made with the Blake-Morscher electrostatic separator, which is reported to have given fairly good results, but not good enough to induce its adoption. The company installed a trial plant of Macquisten tubes which solved the problem of economical metallurgy. The interesting part of the process begins with the separating tubes.

Construction of the Tubes.—The Macquisten tubes are made of cast iron. They are 6 ft. long, 1 ft. in diameter inside, and weigh about 450 lb. each. Externally they are cast with two tires which rest upon the supporting rollers. On the latter the tubes rest horizontally. The discharge end of the tube is entirely open and the feed end is closed, except for a hole in the center large enough to admit the pipe that feeds the pulp. Internally the tube is cast with a helical groove, the form and dimensions of which are shown in the accompanying sketches. The tubes in use at Golconda at the time of operation had an exterior helix of ¾-in. pitch, but it was intended to substitute for them tubes of 1.5 in. pitch, which is a later and improved form that has been found to give better results. The discharge end of the tube connects with a vessel called the separating box, the joint

between the latter and the tube being watertight while the tube is free to revolve. At the side of the separating box, directly opposite to the discharge end of the tube, an opening is cut out for the overflow of the surface layer of water carrying the floating mineral. This opening, or weir, regulates the depth of water in the tube. At Golconda the bottom of the weir is 3 in. above the bottom of the tube, inside; consequently there is 3 in. of water in the tube. The feed of pulp to the tube and the discharge of the tailings from the bottom of the separating box are

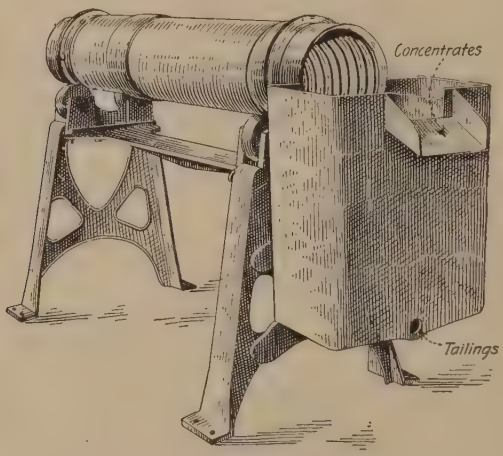


FIG. 5.—THE MACQUISTEN TUBE.

so regulated that the water passing over the weir is about 1/32 in. deep. The tailings flow out through a spigot in the bottom of the separating box, carrying them to a second tube for further treatment, or to the waste dump, as the case may be.

In operation the tube is rotated at 30 r.p.m. in a direction corresponding to the helix of the interior. The pulp is thus screwed through the tube and in its advance is repeatedly given an opportunity to slide upon the surface of the water where it may be retained by surface tension. Considering the pulp lying in any single corrugation; as the tube revolves the pulp is carried up to the surface of the water, some of it to a little

above the surface, and gently rolled over. The angle of emergence is such that some particles of sulphide minerals slide upon the surface of the water, and once that is accomplished they appear to remain on the surface. The gangue minerals simply slide back into the water. This action is taking place in every corrugation, wherefore the minerals that are capable of being upheld by surface tension are given many chances to slide back upon the water at just the right angle. With four tubes in series some of the particles can be observed taking advantage of the chance to float at the very end of the fourth tube. However, the maximum floating occurs in the first tube, and that which takes place in the fourth is comparatively insignificant and is confined chiefly to the larger and consequently more difficultly floatable particles of minerals. It is believed that with the improved tubes, two in series, each 6 ft. long, will be all that is commercially required, and judging from the work at Golconda, this opinion would appear to be correct.

In any given tube revolving clockwise (looking toward the feed end) the flotation takes place chiefly at the left-hand side, where the pulp emerges from the water. The bulk of the pulp in any corrugation either slides back there into the water or floats off; however, a certain amount always adheres to the tube and is carried over to the water on the right-hand side where, upon meeting the water, a further flotation takes place, but naturally this is much less than on the left-hand side. Consequently, from the time the pulp enters the first tube there are floating sulphides streaming off from the sides of the tube, which by the time the discharge end is reached form a glistening film covering the entire surface of the water both in the tube and in the separating box. This is quite different in appearance from the black, frothy scum that rises to the surface in acid flotation processes. In separating the chalcopyrite and pyrite at Golconda the surface of the water is covered with a sparkling froth and mineral, the water looking much as if it had been sprinkled with the bronze powder that is employed for decorative purposes. In treating a lead ore there comes off a film of steel gray galena; in treating a zinc ore from Joplin, Mo., there was a film of mustard-yellow blende. The flotation is persistent. Once it has been effected, the mineral remains on the water until the latter has overflowed into the launder, which spouts it into the concen-

trates collecting tank, and even in the latter more or less mineral can be observed floating on the surface.

Results Obtained by the Tubes.—As to the technical results at Golconda, the capacity of a single tube is placed at 5 tons of ore per 24 hr.; consequently the capacity of the mill with its present arrangement is 125 tons per 24 hr. The ore of the Adelaide mine is reported to assay 2.7 to 3.2% copper, but the mill was running on dump stuff that was said to assay only 2.2% copper. Having been ground to 30-mesh size this was concentrated in a ratio of 11:1, yielding concentrates assaying 22% copper, and tailings assaying about 0.2%. This indicates an extraction of a little more than 90%, but refers only to the deslimed ore. The slime was run into a settling pond and accumulated pending the determination of plans for its further treatment. This slime was believed to amount to 30% of the original ore and to be of about the same assay in copper as the latter. Consequently the actual extraction was about 0.10 to 0.9. It was 63%, but it was considered the percentage of slime could be reduced, and of course the percentage of extraction by the tubes will increase directly in proportion as the percentage of slime is reduced.

Like almost every process, this one has its drawback, and as in the case of almost all processes of ore dressing, the drawback in this one is the treatment of the very fine material that in the dry processes is dust and in the wet processes is slime. It is obvious that this new process, wherein the concentrate is floated off on the surface of the water in the most liberal sense of that expression, it will be contaminated by fine slime that does not settle quickly and floats just under the surface of the water. It would appear that this difficulty might be greatly ameliorated by a suitable modification in the form of a settling box, possibly increasing the length of the latter, reducing the velocity of the water passing through it, or otherwise giving the fine slime an opportunity to settle 1/20 of an inch or so below the surface before reaching the weir.

The foregoing description is complete and clear, and does not require additional explanations, which could, at best, only duplicate what Mr. Ingalls has already so admirably explained.

The Wood Surface-Tension Process.—The principle of the Wood process for the concentration of ores is the utilization of

the surface tension of water, either fresh, acid, or salt. The machine for utilizing the process was described by Henry E. Wood in 1912 but since that time has been materially improved. Its application to molybdenite concentration was described by Wood in a paper read before the Canadian Mining Institute, at Ottawa, in March, 1916, from which the following description is taken.

The machine consists of a rectangular structural-steel frame about 5½ ft. high at the back, 5 ft. wide, and 5 ft. long. Supported in and on this frame are a series of feed hoppers and tanks, feed mechanisms, etc., as will be described in detail, and shown in the accompanying drawing. At the highest part, which is the back side of the frame, is supported a rectangular feed hopper made with cast-iron ends and sheet-steel sides and bottom. Front, ends, and part of the back are vertical. About two-thirds of the back slopes to the front at an angle of 45°. The bottom of the feed hopper is about 4 in. wide and 4 ft. long, and is made of a removable steel sheet that is used as one of the feed-opening adjustments. On the front of the hopper is a vertical movable gate which, in combination with the bottom, gives a wider range of adjustment of the feed openings. Inside the hopper is a longitudinal shaft studded with short pins, which is revolved at the rate of 80 to 100 r.p.m., and serves to keep the ore in the hopper loose and free from channels.

Suspended from the upper frame members by means of flat hickory strips is a triangular truss with cast-iron ends. This truss carries the feed bar which is made of angle-iron and wood, carrying a number of 3½ x ¼ in. screws which project into the feed openings of the hopper. Below the feed bar in the truss is supported an adjustable feed pan 8 in. wide and 4 ft. long that receives ore from the feed hopper as it is delivered by the feed bar. The truss carrying the feed bar and feed pan is vibrated in a horizontal plane by means of a small eccentric attached to the main frame of the machine and connected to the truss by means of a flexible hickory drive rod. The eccentric shaft is driven at about 500 r.p.m. The ore dropping at the back of the feed plate is spread out into a thin, even sheet by the time it has traveled 8 in. at right angles to the vibrations, and is then dropped on to the surface of the water that is contained in the main tank, which is a rectangular inverted pyramid.

The main tank is supported in a frame at ends and back, has a valve at the point or bottom, above which is a diaphragm to steady the flow of tailing that collects in the tank. At the front of the tank is a partition that has its top edge ¾ in. below the

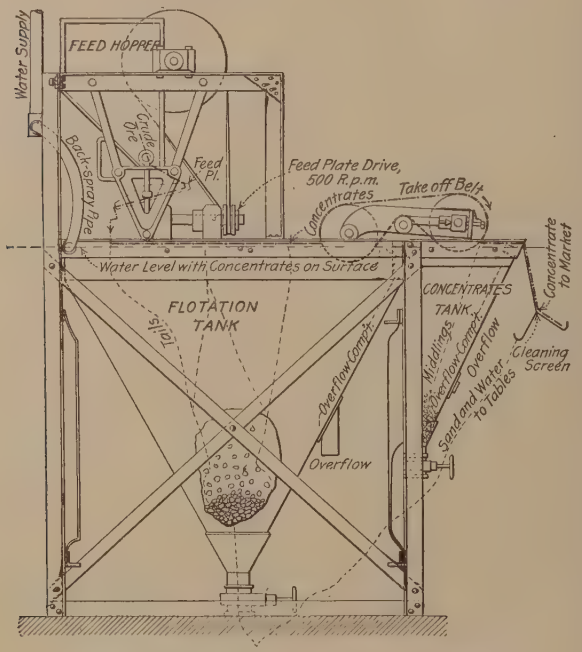


FIG. 6.—THE WOOD SURFACE-TENSION MACHINE.

top of the tank. This edge is an overflow weir and maintains a constant level of water in the tank. At the back of the tank is supported a spray pipe which discharges a large number of fine jets of water parallel to and just below the surface of the water contained in the tank, thereby creating a swift and smooth surface current toward the front of the tank. Halfway between the back spray pipe and the front of the tank is a second spray pipe with a smaller number of holes that assists the back pipe to maintain the surface current uniform clear across the tank. In front of and bolted to the main tank is a narrow rectangular cone

that has a bottom discharge and an overflow weir as in the main tank. The joint between the tanks is made watertight by means of light iron channels set over the top of the joint. Supported on top of the main frame directly over the joint of the tanks is a take-off or concentrate-collecting device, which consists of two 6 in. by 5 ft. rollers and one 2½ in. by 5 ft. roller, supported at the ends by adjustable arms. Around these three rollers is passed a heavy fabric belt that picks up the concentrate from

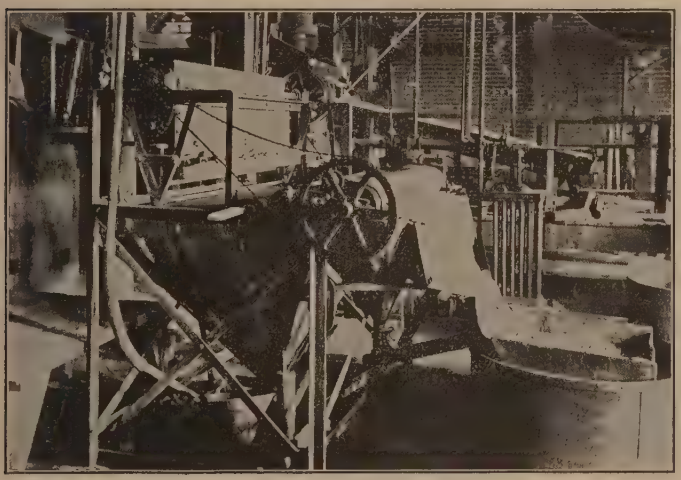


FIG. 7.—THE WOOD INSTALLATION.

the surface of the water in the main tank, carries it over to the concentrate tank where it is washed off on to the surface of the water in that tank and passed on over the weir to a settling or filtering device. The main shaft of the machine is belt-driven and may be connected with any suitable source of power. The roller in the feed hopper and the take-off rollers are driven by chain and sprocket gearings. The eccentric shaft for vibrating the truss is driven by a small round leather belt. The power required is about ¼ h.p., and the water required varies from 5 to 10 gal. per minute. A partially submerged corrugated rubber cylinder is sometimes substituted for the moving plane of water.

Operation of the Wood Machine.—In operation, the dry

crushed ore, sized or unsized, falls from the hopper to an inclined vibrating plate and thence to the surface of moving water in the tank. Adjustments can be made permitting the ore to fall from a minimum of ¼ in., up to a maximum of 4 in., depending upon the size of the material. A — 10-mesh ore would all penetrate the surface film if dropped 4 in., while in falling only ¼ in. in the molybdenite will float upon the water and the gangue will sink. A — 30 or — 40-mesh ore requires a greater

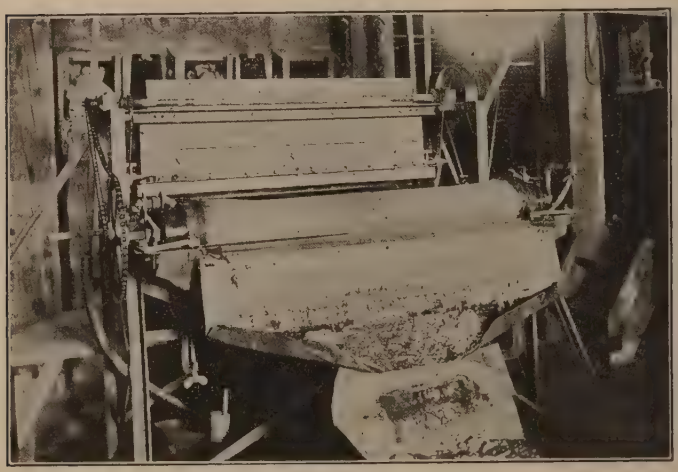


FIG. 8.—THE WOOD INSTALLATION.

fall, so that the individual particles will meet the water surface independently. If the minimum drop is used with such fine material, much of the gangue would land on floating portions of the mineral, and not having a chance to be wetted, would contaminate the concentrate. Jets of water under control keep the surface of the water in motion across the tank toward the take-off belt, so that an area of fresh-water surface is always ready for the falling feed. While passing over the surface of the tank, most of the gangue is wetted and sinks. The molybdenite film adheres to the emerging belt, is lifted out of the tank, and at the point where the belt reverses its traveling direction, it meets the level of water in a smaller tank and leaves the belt. Crossing a

few inches over this second tank, it falls upon a nearly vertical dewatering screen of the same mesh originally used in crushing the ore.

The result of this treatment is that the film of molybdenite is taken away from the greater portion of the gangue, which either sinks or is suspended in the main tank. Such particles of partially wetted gangue as are forced on to the belt become saturated en route and are dropped into the second tank as a middling product. This is often as clean as the other tailing, but if molybdenite is there to any appreciable extent, it is reserved for retreatment. Particles of gangue and gangue in suspension, that are not dropped in the second tank, readily pass through the meshes of the inclined screen and also constitute a middling product. Both of these middlings are usually of small proportions by weight and should be considered as part of the material to be cleaned by retreatment. In some cases the additional wetting of the gangue, as well as drying the exposed sulphide, is so marked that canvas-covered cylinders are placed in the main tank, the film being lifted up twice and deposited twice before it arrives at the main take-off belt.

The adoption of this plan produces such clean concentrates that it is not necessary to treat again the main product, as has to be done to raise the grade. The molybdenite is diverted to suitable concentration boxes, dewatered by decantation or filtering, and after drying is ready to be sampled, assayed and shipped. Some of the smaller tests reported herewith were made from ore crushed at — 10, — 12, — 16, and — 20-mesh, and when these reach a 30- or 40-mesh final-cleaning screen particles of gangue are too large to pass through it, being collected with the concentrate and thereby lowering the grade of the latter. The small machine used for the preliminary investigation has a 10 in. exposed belt surface as against 54 in. in width, of the commercial concentrator. It also has but about one-half of the length of the flotation period provided in the large machine. As a result of these two factors, a commercial machine usually gives better result than a small laboratory device. The gangue and any associated mineral, not so readily susceptible of flotation as molybdenite, passes through the film and becomes dependent upon gravity conditions for separation. In the preparation of the ore, molybdenite flakes may have lost their original tabular

shape, or for other reasons be not adaptable to flotation. On this account, the tailing after flotation passes to a Wilfley table. A concentrate is obtained that carries the coarse molybdenite as well as other minerals of value such as copper, free gold, tungsten, etc. The Wilfley concentrate is subject to retreatment for additional molybdenite as well as the other minerals mentioned. Satisfactory adjustment having been made, the operation of the machine then becomes automatic and requires only the usual attention given to milling operations.

The Capacity of the Machine.—The capacity of the machine is mainly dependent upon two conditions, that is size of ore treated and the ratio of concentration. The surface area of the water in the tank can sustain only a definite weight of concentrate, and to overload it will cause the mineral to sink. The water film is elastic and the concentrate very compressible, so that it will sustain a much larger weight than seems possible. A sheet of water 38 x 38 in. will support 1.55 lb. of molybdenite. From this it is evident that excess feeding and overloading must be avoided. To increase the capacity as effected by such conditions would necessitate a greater area of tank surface, so that with other parts of the machine in proportion, a greater amount of ore could be milled per machine. It is merely a question of how wide a feed plate and take-off belt can be safely operated. A 0.5 to 1% molybdenite ore with a gangue that is quickly wetted, such as clean quartz, will pass through very rapidly when crushed to ordinary sizes. The feed may be sized or unsized, but if a sized feed is given, it will pass through at a much greater rate. The machine now in use, with feed and take-off belt of 52 in. width will treat a 1% molybdenite ore at a rate varying from 10 to 20 tons per 24 hr. A 10% to 20% or better ore will go through at a much less rate, in proportion to the tank area. Other minerals frequently float and take up just as much space as molybdenite, as for instance chalcopyrite. When it is present it requires a second treatment, when the partial oxidation caused by the intermediate heating and drying will cause it to sink, while the molybdenite which does not oxidize so readily, will float. Under usual conditions, the capacity of the machine will vary from 4 to 15 tons per day.

The Minerals Separation Process.—The system of flotation now utilized by Minerals Separation is a development of the oil-

and-air-froth system by means of which a mixture of pulp, oil, air, and sometimes acid is violently agitated, producing a froth that floats and carries the mineral particles along with it. The machine now principally in use is a development of many workers with many ideas, but possibly the original Hoover machine had more to do with the present result than any other. The

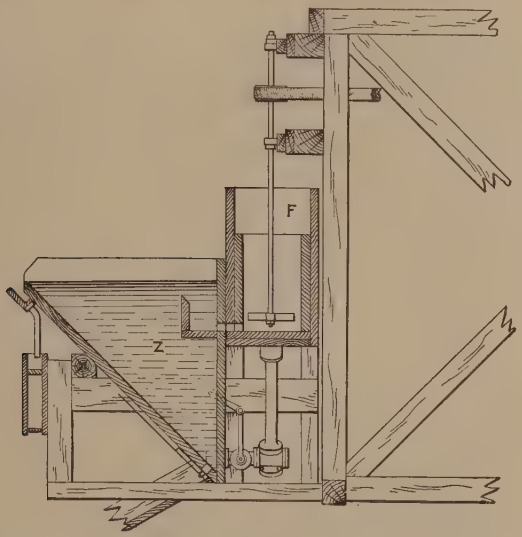


FIG. 9.—A SECTION OF THE HOOVER SINGLE-LEVEL APPARATUS.

accompanying sketch shows the essential principle of the machine, a development of the original machines.

At *F* is a mixing compartment containing an agitator running at high speed; *Z* is the spitzkasten. The ore, water, oil, acid, and sometimes steam, if it is required for raising the temperature of the pulp, are fed into the mixing compartment in proper proportions where the pulp is thoroughly mixed and violently agitated. *F* has a hole in the bottom which allows the pulp to pass into the next compartment where there is more violent agitation. The pulp passes from this into another agitation compartment and then goes over a weir into the spitzkasten where a heavy, dense mineral froth is floated over the lip. The gangue

along with some of the sulphides, passes to the tip of the spitzkasten *Z*, the tip being connected by a pipe with the bottom of another agitation compartment. The agitator in this compartment acts as a centrifugal pump and draws the material up into the compartment where the pulp receives further agitation and

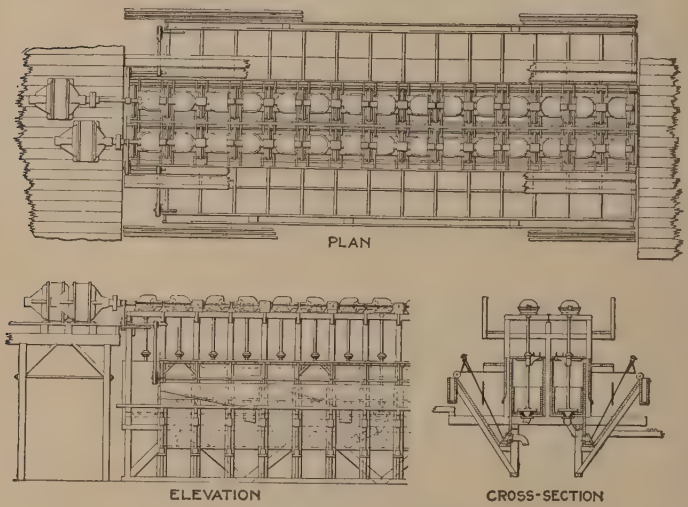


FIG. 10.—THE MINERALS SEPARATION MACHINE AT ANACONDA.

aeration. The operation of the machine then is simply a repetition of agitation and skimming from the spitzkasten.

Present Minerals Separation Machine.—The Minerals Separation machine as used at the present time is somewhat different. A description of the installation at the Washoe Reduction Works of the Anaconda Copper Mining Co. will illustrate the construction of the modern machine and its operation. The accompanying drawing shows the machine as it is installed. The feed is introduced into the first agitator box at the motor end of the machine. From this box it passes to a second box through an opening in the partition,—shown on the elevation drawing. From this second agitating compartment, the pulp passes into the first spitzkasten where the first concentrate froth is removed by means of a paddle and the remaining pulp passes through a pipe, the inlet to which

is controlled by a valve, to the third agitating box. From this agitating box the pulp passes to the second spitzkasten, and so on down through the machine until the pulp is introduced into the fourteenth spitzkasten. The discharge from the fourteenth or last spitzkasten leaves the machine as tailing. The first four to seven spitzkastens make finished concentrates and the remaining spitzkastens make middlings that are returned to the system.

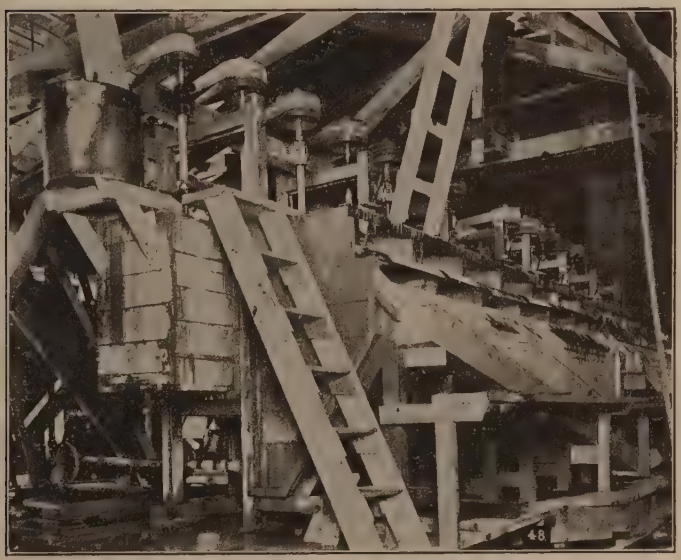


FIG. 11.—A FLOTATION INSTALLATION OF THE MINERALS SEPARATION TYPE AT A COLORADO TUNGSTEN MILL.

The drawing shows a double machine, each machine, however, being run as a separate unit. The line shaft is driven by a 150-h.p. motor at a speed of 385 r.p.m. The machine under a load requires about 100 h.p. The vertical shaft carrying the impellers revolves at a speed of 223 r.p.m. The impellers are the usual Minerals Separation type, having four blades placed at 45° to the vertical. They are 2 ft. in diameter. Each pair of impellers is arranged so that one revolves in one direction and the other in the opposite direction. This tends to balance the side

thrust on the line shaft. The bevel gears that drive the impeller shaft are cut steel and run in grease. The impeller shaft is supported both vertically and horizontally by ball bearings. In some cases it has been found of advantage to place the motor on the other end of the machine from that shown in the drawing, especially if it is necessary to heat the pulp to over 100° F.

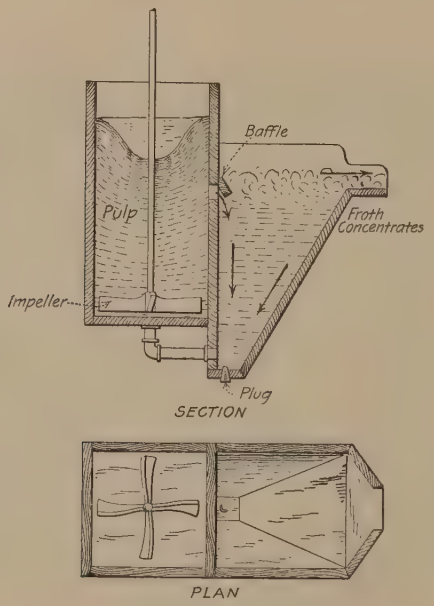


FIG. 12.—A MACHINE OF THE HOOVER TYPE.

There is more or less steam arising from the pulp, especially at the feed end, which condenses on the motors and by placing the motor at the discharge end this trouble is practically eliminated.

Each machine makes three products, concentrate, which goes to the dewatering division; middling, returned to the head of the machine, and tailing, to waste. Concentrate is taken from the first three to five spitzkastens and middlings from the last nine to eleven. A portion of the pulp is overflowed from the last three spitzkastens, together with the froth. About 6 to 8 lb. of 50° Baumé sulphuric acid per ton of flotation feed is used,

together with 2 to 3 lb. of kerosene sludge acid and ½ to 1 lb. of crude wood creosote.

A portion of the wood creosote is added ahead of the Hardinge mill (about 0.03 to 0.05 lb. per ton of feed), and the remainder is added in the six agitating compartments. The sulphuric acid and sludge acid are added at the head of the machine. The pulp is heated to from 60° to 70° F. by passing live steam into it at the head of the machine. Three machines are used for treat-

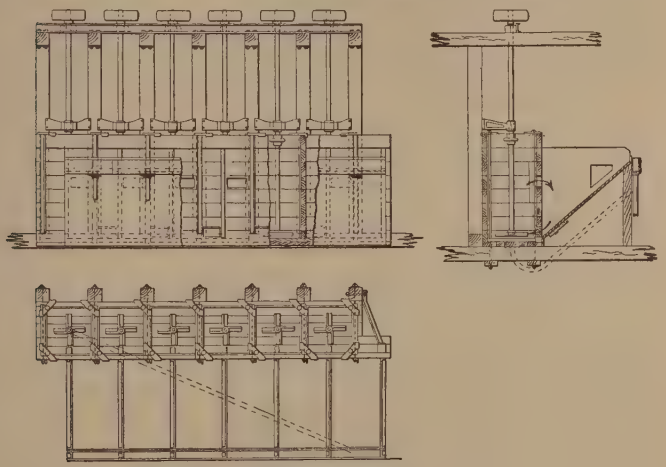


FIG. 13.—IMPROVED HEBBARD MACHINE.

ing sand, and the fourth for treating current slime from the upper portion of the mill. Each machine has a capacity of about 400 tons per day on sand, and 175 tons per day on slimes.

The plant treating slime consists of 20 Minerals Separation machines of the same type as those used in the concentrator, and five 20 x 12 ft. Dorr tanks are used for dewatering the concentrate. It is noted that the treatment of slime from the dump offers a few more difficulties than that of the current slime. The former has been exposed to the weather for a number of years, so that the copper is partially oxidized, consequently that portion probably cannot be floated. At Great Falls, one double Minerals Separation machine of the same design and size as used at Anaconda is treating from 300 to 350 tons of dump slimes daily.

Other Minerals Separation Machines.—The machine used by Minerals Separation varies in different plants. Different ideas have been developed by the operators on the staff of Minerals Separation and outside inventors who have transferred their ideas to that company. One of the important modifications is known as the Hebbard machine, one of the late developments of which is in principle similar to the Hoover. The vital difference between the Hebbard and Hoover types is that in the former dependence is not altogether placed upon the beating of atmospheric air into the mixture while agitation is taking place. On the contrary, a pipe containing air under small pressure is led to a point just beneath the agitating or beating mechanism in the pulp, and a stream of air is delivered to that part. Naturally a far larger quantity of air can be beaten into the pulp in this way than if dependence were placed merely upon the vortex action of the title, as it draws air upon the surrounding atmosphere. The Hebbard machine, like the Hoover, was originally intended to be driven from the top, but the Harvey improvement is one by means of which the drive is arranged from the bottom, beneath the flotation apparatus. This is said to be a considerable convenience in many cases, and such an arrangement is in practical use at the new zinc plant installed by the Sulphide Corporation at its Central Mine, at Broken Hill, N. S. W.* The plant has a capacity of about 4000 tons per week. The boxes, or frothing machines, are fitted with special stirrers to agitate and aerate the pulp, creating a froth containing only lead concentrates. Having removed all the lead possible by this means, the pulp passes to other boxes, or frothing apparatus, where sulphuric acid and oil are added. Agitation and aeration take place as before, and the blende is recovered. There are altogether ten boxes, three for lead and seven for zinc.

The Louis A. Wood Machine.—Another machine that has been taken over by Minerals Separation is that of Louis A. Wood, which has been patented. The apparatus is shown in the accompanying drawing. A paddle agitator is provided, the pulp entering from one side and air from another. The whole mixture is forced upward and through the small opening in the first chamber, where a middling is formed, which settles back into the air pipe and is forced again into the agitating chamber. The upper

* *Min. and Eng. Review*, Dec. 6, 1916.

chamber receives the clean sulphides, which are then floated nearly to the top of the machine.

Air bubbles containing sulphides and without any oil will not persist to the surface of the pulp, but will break at or below it. This machine is intended to be used without any oil. To receive this sulphide, which sinks from the broken bubbles, the

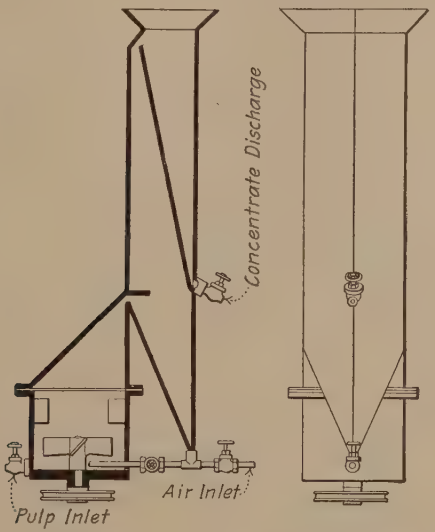


FIG. 14.—THE L. A. WOOD FLOTATION DEVICE.

upper chamber with the inclined bottom is devised. The concentrates are drawn off through the valve at the apex of the chamber. Agitation and air injection are at such a rate that the bath gangue will not pass out of the agitating chamber. A special opening near the bottom of the chamber is provided to draw off the tailings. The accompanying drawing shows clearly the construction of the apparatus.

The Callow Bubble-Column Process.—The Callow flotation process is one that depends upon the making of a froth from oil and air, with or without the addition of acid or other chemicals. Instead, however, of producing this froth by means of violent agitation, as is done in most machines, it is produced by a

thorough preliminary mixing of the oil and pulp and whatever other ingredients are used, and then the forming of the actual froth in the special Callow device by means of finely divided air bubbles. A description of the process was given by J. M. Callow, its inventor, to the Feb., 1916, meeting of the American Institute of Mining Engineers at New York, and from that description the following explanation is, in great part, taken.

The various elements composing the Callow process are shown in the accompanying drawing. In the mixer, *A*, operated by

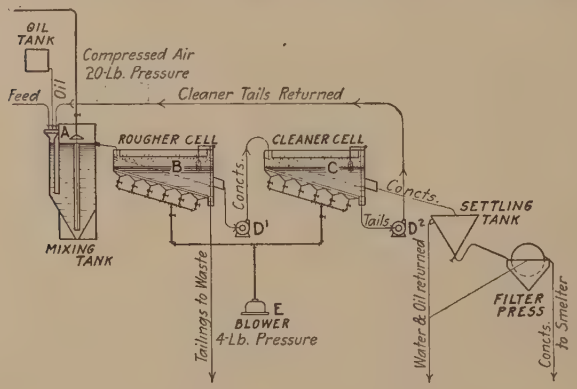


Fig. 15.—Illustration of the Callow Process.

compressed air, the oil, air, and water are mixed and agitated. In cases where the oil or frothing agent can be fed into a crushing or grinding machine, this mixer or Pachuca tank, can be dispensed with, the tube mill discharging the mixture to the separatory cell.

The initial or roughing separatory cell *B* consists of a tank about 9 ft. long and 24 in. wide, with a bottom inclined at from 3 to 4 in. to the ft. It is 20 in. deep at the shallow end and 45 in. deep at the other end. It may be built of either steel or wood, but wood is preferable. The drawing shows the cell in detail. The bottom of the tank consists of a porous medium made of four thicknesses of loosely woven canvas twill, properly supported by a backing of perforated metal to prevent exploding when under air pressure. Through this porous medium com-

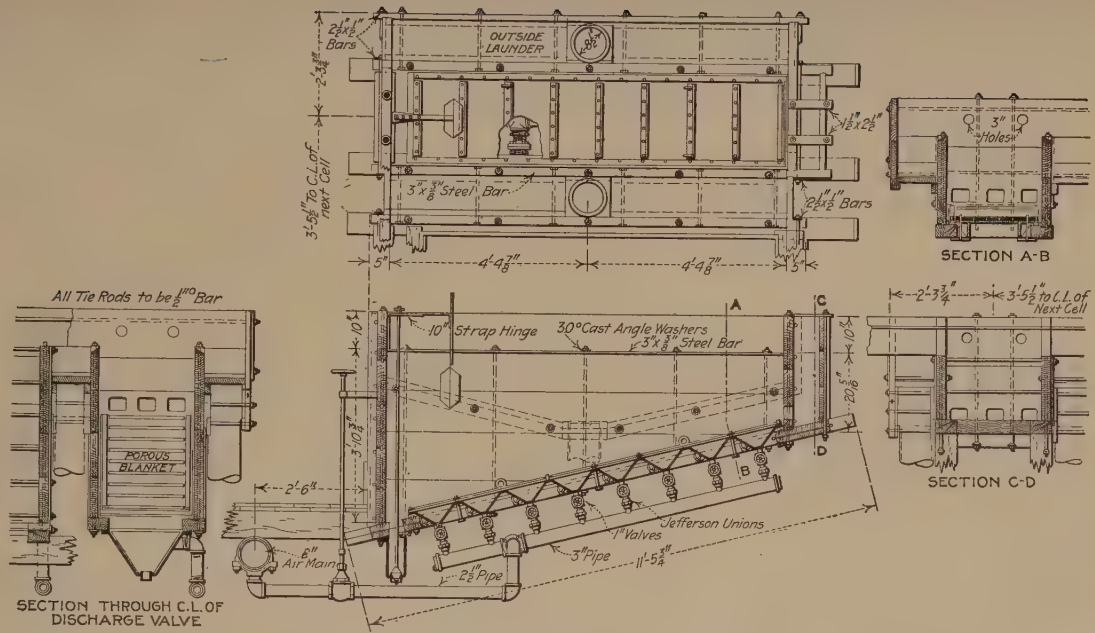


FIG. 16.—THE CALLOW BUBBLE-COLUMN APPARATUS.

pressed air is forced by a blower. Porous brick or any other ceramic material that will give the necessary fine subdivision to the air, may also be used. Some of these have been tried out, but for practical and mechanical reasons the loosely woven canvas twill seems to serve all purposes better than anything else. The space underneath this porous bottom is divided into eight compartments, each connected by an individual pipe and valve with the main air pipe. By this means the air pressure to each compartment can be regulated (by throttling the valve) to correspond to the varying hydraulic head in the tank and so as to discharge a uniform amount of air throughout the length of the bottom. A pressure of from 4 to 5 lb. is commonly used, each square foot of porous medium requiring from 8 to 10 cu. ft. of free air per minute.

Each longitudinal edge of the tank is provided with a lid and an overflow gutter for the reception of the froth discharged. The lower end of the tank is provided with a spigot discharge fitted with a plug valve, operated by a plug, to maintain a uniform water level within the tank and thus, in turn maintain a uniform and constant discharge of froth under all the varying conditions of feed supply incident to practical milling operations. The water level may, of course, be varied, but is usually maintained at about 10 to 12 in. below the level of the overflow lift. The tailing is discharged through the spigot, and the frothy concentrate is conveyed to the cleaner separatory cell, *C*. This cleaner cell is a machine of the same construction as the rougher. In operation, however, it usually has a lower air pressure. The tailing from the cleaner is returned to the original feed, a closed circuit being thus maintained. The concentrate from the cleaner is the finished product.

The machine may be run either in parallel or in series without any sacrifice in the capacity for a given number of cells. Recent experience goes to show that on some ores the series treatment gives slightly cleaner tailings; on others it does not. It is not necessary to extend this arrangement of cells beyond two cells in series. In a heavily mineralized ore this arrangement is practically advantageous, but in such a case the rougher concentrate might be of high enough grade to dispense with the cleaning operation. The froth from the second cell in the series might be returned to the original feed in the same way that the tailing is

returned from the cleaner when practicing a roughing and cleaning operation. A number of such operations and combinations are possible. The froth is generated as a result of injecting the finely divided air into the bottom of the already highly mixed pulp; it continues to form and to overflow as long as it is provided with pulp of the proper consistency, adequately mixed with the right quantity and kind of oil or frothing agent. Measured from the water level within the tank, the froth produced may be from 14 to 16 in. thick, but will be more or less voluminous, coarse or fine grained, dry or watery, according to the character of the ore and the kind and quantity of oil or ore introduced.

The condition of the froth may be varied, therefore, by changes in the kind and quantity of oil used and the quantity of air injected. In some ores rich in sulphide, and where a comparatively low-grade concentrate will suffice, the cleaning cell may not be necessary, but on low-grade ores having a higher ratio of concentration and when a concentrate of extreme cleanness and of maximum grade is required, a cleaner is desirable.

Density of the Pulp.—The pulp to be treated may be of varying density, from 2½ of water to 1 of ore, up to 5 or 6 to 1. For a mixture of sand and slime, the former ratio is preferable, but for pure, minus 200-mesh slime, the larger proportion of water is allowable. The particular density is not a matter of so much importance as the supplying of pulp of uniform density, since each variation in the density of pulp requires a readjustment of the oil supply, the quantity of oil increasing in proportion to the increased volume of the pulp, independent of its solid contents.

In the Callow process, as in other flotation systems using oils, the latter may be broadly divided into frothers and collectors. The pine oils are good frothers, and coal tar and its various subdivisions are good oilers. On some ores crude pine tar will in itself combine the properties of both frothing and collecting; on others this may have to be enriched by the addition of some one of its more volatile constituents, such as refined pine oil, turpentine, or wood creosote.

Generally speaking, the coal-tar products are poor frothers, and to get a sufficient volume of froth to insure high recovery, it is often necessary to add refined or crude pine oil, creosote, etc. At the Inspiration mill, where the Callow process is used, the

mixture is 80% crude coal tar, and 20% coal-tar creosote; at another plant on similar ore, 45% El Paso coal tar, 40% coal-tar creosote, 10% creosol, and 5% pine oil. At Daly-Judge a mixture of 40% crude coal tar, 40% creosote, and 20% pine oil was used. In the Coeur d'Alene on zinc ores straight wood creosote was used; on the ore of the National Copper Mining Co., plain turpentine will work, but pine oil is better.

Various quantities of oils are used, according to the ores to be treated. In experimental work the stability of bubbles depends to some extent upon the oil used and the nature of the gangue in the pulp treated. The character and characteristics of oils are, however, described in another section, so it will be unnecessary to devote space to that explanation here.

It will be noticed that in the application of the Callow process, the preliminary mixing, or, as it has been wrongly called, "emulsification," is performed in a Pachuca tank. This tank is a device that has been lifted bodily from cyanide practice, where it is used for agitating the slimes in contact with cyanide solutions. After a trial, in practice, however, it has been found that the tank may be omitted with perfectly satisfactory results, the mixing secured in the grinding and conveying sections of the mill, amply meeting all the requirements.

As a side remark, bearing on the wrong use of words that is too common in our technical literature at the present time, it is proper to object to the use of the word emulsification as synonymous with mixing. The two operations are essentially different, and results obtained after the application of one process may be radically changed if the other is used. However, a discussion of this point occurs in the section devoted to the theory of the process, where the matter is thoroughly thrashed out.

It is to be noted that in the application of the Callow process, the first operation, that of roughing, is devoted to the securing of clean tailings. Since it is almost certain that clean tailings and clean concentrates cannot be obtained in one operation, in the roughing process the grade of concentrate is sacrificed to the cleanness of tailings. Tailing should be clean enough, that is so reduced in value by this first operation, that it can be thrown away at once. The cleaning operation, performed in the next cell, is then devoted to securing a high-grade concentrate, with a medium middling, the middling being retreated and sent to

the head of the box an indefinite number of times, so that the final product is clean tailing and clean concentrate with no middling at all.

The Murex Magnetic Paint Process.—The Murex Process, while not strictly a flotation system, depends upon the selective adhesion of oil to mineral particles, and therefore may properly be considered in the study of flotation processes. The Murex process depends upon the fact, as has been said, that oil adheres to mineral particles, but in this case the oil is highly charged with magnetic iron oxide, which is thus painted upon the mineral-sulphide particles. Finely ground magnetic material such as filings of iron or ground magnetite or pyrrhotite, is mixed into the oil before it is added to the ore pulp, and when the oil adheres only to the sulphide minerals, the effect is that they receive a coat of magnetic paint. By using a magnetic separator adapted to slime separation the particles of sulphide are lifted out of the pulp away from the non-magnetic gangue. Material of sizes hardly regarded as slimes, such as particles two or three millimeters in diameter, can also be treated in this way.

In preparing the oxide or magnetic mineral, it should first be ground to an inpalpable powder, just as paints are made. In this way it is assured that a minimum quantity of the material will cover a maximum area of mineral sulphide particles.

The process has been tested out in the Bergwerks-Wolfart,* Clausthal, in the Harz Mountains of Germany, as well as at the Whimwell Mine in Australia. Fairly satisfactory results have been obtained, though occasionally baffling difficulties were encountered. The magnetic paint, which is made up of oil-gas tar mixed with twice its weight of finely ground cast iron (any animal, mineral, or vegetable oil can be used, or even a fatty acid, soap, or other such material) is applied in a horizontal rotating cylinder resembling a tube mill except that it is lined with blocks of wood set end on end. The mill contains iron or lead shot and pebbles and the discharge is preferably at the periphery of the end. The metal balls, which are about ¼ in. in diameter, become coated with the paint which they in turn rub on to the surface of the ore particles. The function of the pebbles is to prevent formation of granules of oiled minerals or any other lumps or

* Oliver C. Ralston, "Control of Ore Slimes," *Eng. and Min. Journal*, April 29, 1916.

agglomerations, and to prevent the shot from sticking together. It is best to give the pebbles a coating of paint before they are put into the mill. The shot are inspected from time to time, and it has been found that so long as they are well coated the process works satisfactorily. In case the ore requires grinding, the operation can be carried on in an ordinary tube mill.

Some difficulty was encountered in the tendency of ground magnetite or other material to leave the oil and go into the water. One of the patents, however, covers the method of preventing this loss of magnetite by using certain additional agents with the oil when the magnetic paint is made up. When using saponifiable oils, all that is necessary is the use of any sulphate, chloride, sulphide, hydrate, or other salt soluble in the oil or which forms insoluble soaps with the oil. In case the oil used is a mineral oil that will not saponify, it will require, in addition to the salt, a small amount of soap or saponifiable oil. A small amount of a solution containing 1 to 5% of alum, mixed with the oil, has been found to do good work.

With some ores, it is found that an acid solution works best, and with other an alkaline solution. As a mineral froth does not have to be formed, this process can work through a wider range of solutions than can the flotation process. The plant at Wolfart used a neutral solution and treated a galena ore containing 10% lead, while the Whimwell plant used an alkaline solution and treated a copper ore containing sulphides and carbonates.

The Theory of the Murex Process.—The underlying theory of the process is undoubtedly much the same as in the flotation process, wherein certain minerals are coated with oils while others remain uncoated. In fact it has not been proved that the Murex process will treat any ore which the flotation process cannot treat, unless we accept Hyde's statement that under proper conditions it is possible to treat lead carbonate by the process. In this connection Hyde probably had in mind U. S. patent No. 996491, taken out by Lockwood and assigned to the Murex company, in which is given a method of applying the Murex process to the concentration of oxides and carbonates. This consists of the use of a soluble alkaline sulphide in solution to form a film of metallic sulphide over the surface of the carbonate particle by

reaction with it. Thus the reaction with lead carbonate of an ore is as follows:

$$PbCO_3 + Na_2S = PbS + Na_2CO_3$$

Lockwood gives two examples of the method of working. A hundred pound lot of ore containing carbonate, phosphate, and chloride of lead was crushed to pass at 24-mesh screen and then suspended in 80 lb. of water. To this was added 4 lb. of finely ground magnetite in two pounds of Texas residuum oil. After agitation for about ten minutes, a solution containing about 3 oz. potassium sulphide was added. A film of lead sulphide was formed on the oxidized lead minerals and they were successfully coated with magnetic paint ready for separation. The second example is of the sulphide filming of a carbonate ore of copper—likewise successful.

As the sulphide filming of carbonate ores of lead and copper is now meeting with considerable success in the flotation process, it may be said that the Murex process has a limited field. Lockwood has presented a method of treating slimes of mixed materials in order to avoid having to grind them further. Middlings of galena and sphalerite can be treated with a solution of caustic alkali and silicate of soda with the result that the galena and sphalerite separate along cleavage lines without the need of further crushing. Supposedly this is due to the tendency of sodium hydrate and silicate to disperse a suspension of negatively charged particles. The increase in degree of dispersion of clays by the use of these chemicals is fairly well known. After feeding the galena and sphalerite in this way, they can be separated on a slime table or on a vanner. He proposes the same method in tabling of mixed zinc lead flotation concentrates.

Lockwood gives, as an example of this method applied in the treatment of ore, two tests that were run on two tons of ore from the Broken Hill Proprietary. The ore was crushed to about 40 mesh and divided into two lots. One lot of 2,240 lb. was treated with 500 lb. of a solution containing 5% of caustic soda and 1% of sodium silicate. After agitating for thirty minutes, the pulp was fed onto shaking screens, and the material remaining on the 60- and 80-mesh screens was run over vanners. The results are shown in the first table. With the other lot of 2,240 lb., the same conditions were observed except that pure

water was used on the ore. The results are tabulated for comparison.

SEPARATION BY USE OF SODIUM HYDROXIDE

Concentrates				Middlings
Wt., Lb.	Size	%Pb	%Zn	Wt., Lb.
103.5	On 60	76.8	3.9	43.5
172.0	On 80			36.5

COMPARISON BY USING PURE WATER

Concentrates				Middlings
Size	Wt., Lb.	%Pb	%Zn	Wt., Lb.
On 60	88	72	6.5	130
On 80	134			68

Lockwood examined the middlings in each instance and found that in the case of the dispersed pulp, they seemed to be made up of free crystals of galena and sphalerite, while the middlings from the test in water seemed to be true middlings, containing composite particles of the two sulphides that required further grinding. It is quite possible that floccules containing both sulphides could be dispersed by the sodium salts and that it was hence easier to get a good clean tabling test on this account. The idea certainly merits further investigation.

CHAPTER VI

TESTING ORES FOR FLOTATION

Like all other details pertaining to flotation, the procedure of testing an ore to determine its availability for treatment by the process has not been reduced to a definite series of operations. There are a multitude of ways in which the tests may be made, and it seems probable that satisfactory results can be obtained by any of them, provided they are carried out with judgment and with a view to the peculiar requirements of the ore under investigation.

In treating of the subject of testing ores by flotation, Hoover * advises that for one who has never undertaken such tests the best results would be obtained by starting with a very simple ore, upon which the process is clearly and easily applicable. He mentions a mixture composed of about 60% quartz and 40% hornblende, or 70% quartz and 30% of pyrite or chalcopyrite. He calls attention to the fact that these mixtures are not common in nature, but can be closely approximated by some well-known ores. This seems to be a fairly good way to start out since it will enable the operator to become acquainted with the action of ores under flotation tests; with the appearance and character of froths, and with the mechanical manipulations necessary to secure satisfactory results from the work. Of course, in carrying out tests of this sort, some equipment is required, but very good work can be done without any serious outlay for machinery. It seems, then, a reasonable method of explanation to begin with the machines and appliances that may be used for testing ores by the flotation process.

The Requirements for Flotation Tests.—Since the requirement for effecting flotation is a combination of oils, finely ground ore, water (and perhaps acid or some other agent in the solution), and a method of thoroughly mixing the whole, it may be

* "Concentrating Ores by Flotation," page 62.

seen that they are rather easily fulfilled. Successful tests can be made by shaking up the combination in a bottle or in a Mason fruit jar, but these appliances have the objection that the separation of concentrates from tailings is not easy.

As a first step in progression beyond the period of shaking a bottle, the separating funnel, a rather common piece of laboratory apparatus, has been successfully used for the purpose. Its use is described by Ralston and Allen,* who show that by giving a thorough shaking in a separatory funnel the froth can be formed, and the appliance has the additional advantage that the tailings and water can be drained off through the stem of the funnel, leaving the froth and concentrates in it. A sharp line of demarcation can be taken advantage of with this appliance. It has the additional advantage that, being made of glass, the operation is visible at all stages, and judgment can be used as to when agitation has been carried to a sufficient point.

The Slide Machine.—Perhaps next device in order of importance is the slide machine that was invented by Hoover and perfected by a series of others since his time. As described by Hoover in his book already referred to, this machine is made in two parts, an upper one *A*, and a lower one *C*, both sliding easily on the rubber cushion *B* between the two parts, or, better still, having the bearing surfaces highly polished. The rectangular section of the interior is 4½ in. The upper part *A* has a tail *D*, the purpose of this being to prevent leakage of the froth when the upper half is slid to the right for the purpose of removing it. Windows of glass in each of the two parts enable the operator to watch the progress of the test. At *E* there is a simple agitator with four arms at right angles. The shaft driving this agitator goes to the bottom *G* of the lower part *C*, and is tapped with a small stuffing gland to prevent leakage. At *F* is a hole communicating with the interior at the bottom, closed with a valve. This hole is for the withdrawal of tailings. The agitator arms are 2 in. long from the center of the shaft, thus describing a circle of 4 in. when revolving, and so leaving a clear space of ¼ in. between the ends of the arms and the sides of the interior. The normal speed of this agitator is about 1,500 r.p.m. The machine should be made of some metal that gives a

* "Testing Ores for the Flotation Process," *Min. and Sci. Press*, July 24, 1915.

clean casting. The lower surface of *A*, which rests on the rubber cushion *B*, and the upper surface of *C*, upon which the rubber cushion rests, should be planed and polished smooth. The cushion is a piece of rubber insertion about 1/16 in. thick, and

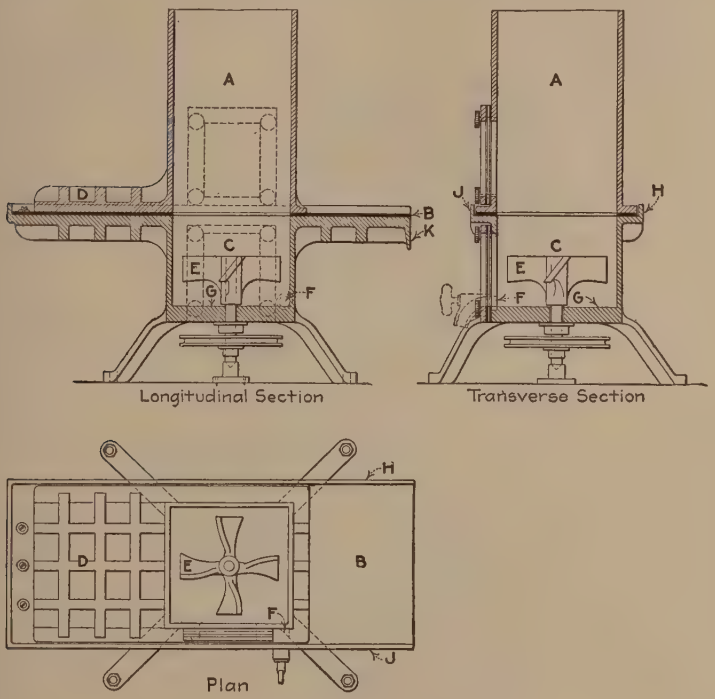


FIG. 17.—THE HOOVER SLIDE MACHINE.

just wide enough to fill the space between the edges *H* and *J*, of the tray-like part *C*. The cushion can be discarded if the surfaces are accurately planed and polished. The accompanying illustration shows the construction of this machine, and its operation, which is simple enough, can be readily understood. After forming the froth by agitation caused by high-speed revolution of the paddle, the froth is brought above the dividing line where the machine separates. Having placed the line of demarcation

between foam and pulp to agree with the division of the machine, the top half is slid off to one side, carrying the froth and concentrates along with it, the tailings remaining in the lower half, from which they may be drained off through the bottom.

Other Experimental Machines.—In addition to the machines already described, miniature copies of the Minerals Separation

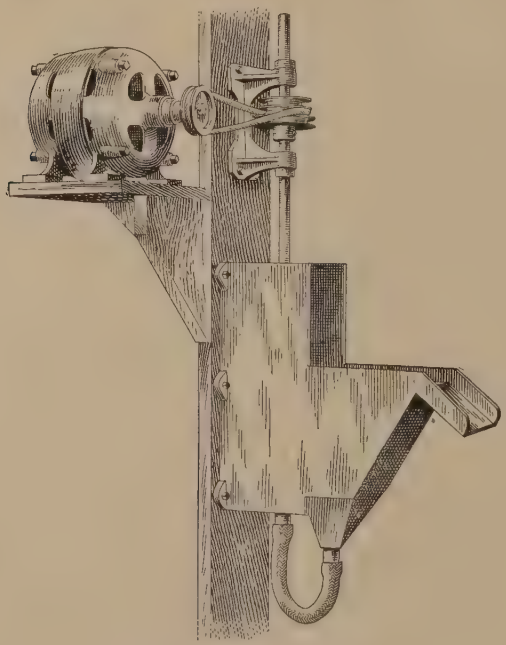


FIG. 18.—CASE TESTING MACHINE.

machine may be obtained for testing purposes, and likewise small models of the Janney, the Wood, the Potter-Delprat, Callow, and nearly all the other devices. The unit in the commercial Macquisten machine is so small that a single tube will serve very well as an experimental installation. Besides these machines there are several made especially for experimental purposes, such as the Case, and that of Roy & Titcomb of Nogales, Ariz. Many experimenters, however, prefer to build their own

flotation machines, and this is a simple matter. It may readily be done by using one of the well-known types as a model and building the machine of wood. The principal objection to the home-made machines is that they usually do not contain glass windows in the sides, although by the utilization of skilful workmanship such conveniences may be incorporated in them.

Flotation Factors of an Ore.—The examination of an ore for its applicability to flotation treatment will involve the study of

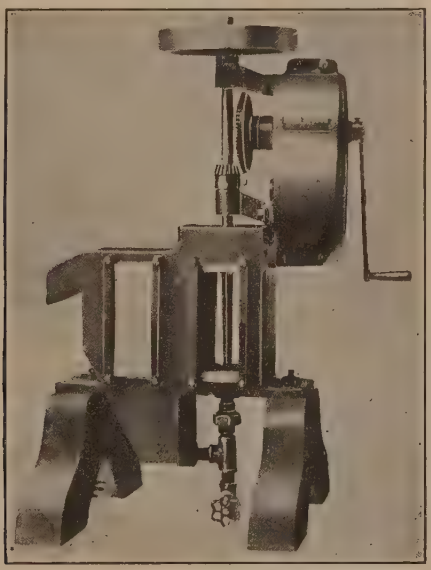


FIG. 19.—ROY & TITCOMB TESTING MACHINE.

about six points. In the order of their importance these are as follows: (1) the size to which the ore must be crushed; (2) the dilution ratio; (3) the temperature at which the solution must be carried; (4) the amount of acid required; (5) the question of oil, this being divided into two parts, the first of which deals with the variety or kind of oil or oils to be used, and the second dealing with the amount required; (6) the agitation required, its kind, duration, and comparative violence.

Before attacking any of these details directly connected with

flotation, of course, it must be ascertained that the sample upon which experiments are to be carried out is a representative one of the ore to be treated. This applies as well to flotation as to any other metallurgical process, and has been so thoroughly insisted upon by metallurgists that there would be no good purpose

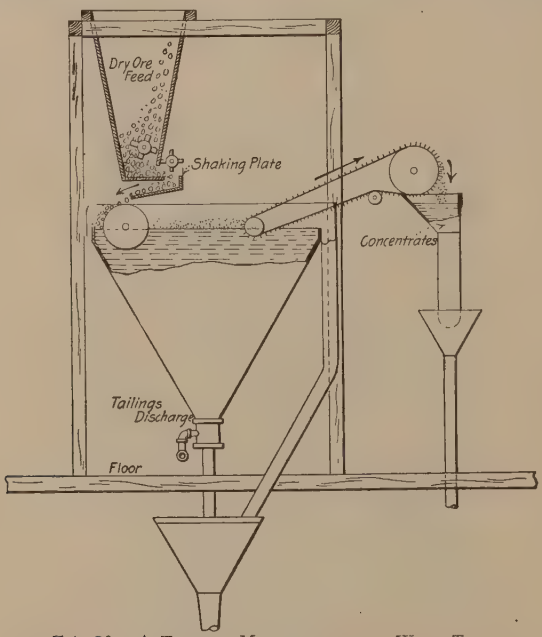


FIG. 20.—A TESTING MACHINE OF THE WOOD TYPE.

served in going further into it here. It is sufficient to say that it is essential to have a representative sample, since without it the metallurgical results, no matter how carefully obtained, are altogether worthless.

In addition to the accuracy of the sample, its condition is also a matter for careful consideration. If material for flotation is in the form of a pulp already ground by milling machinery, then it is essential that flotation tests be carried out on the pulp as it occurs. Should the solids be separated from the mill fluids, a change and opportunities for error are introduced. Should

the solids be shipped to a distant testing laboratory an error is almost sure to occur, since even superficial drying may change the surface conditions of the particles so as to increase or decrease their tendency to float, thereby vitiating the result of any experimental work.

Tests Preliminary to Flotation.—Before attempting flotation, it is also well to carry out a further series by a preliminary series of experiments to determine whether or not part of the ore can be treated by flotation and a part more economically by some other process. This, of course, depends upon the kind of ore under consideration, and with some particular classes the question may be passed over without detailed examination. On many ores, however, it is well to carry out a series of grinding tests to find out whether or not a certain portion of the ore, whether it be the coarse or fine portion or intermediate material, can be discarded without further treatment or can be handled by a treatment which is cheaper than the one under consideration. For example, on many concentrating ores it is found that the portion above a certain mesh—take 40 mesh for example, merely as an illustration—can be classified as to size and concentrated on tables to the best advantage, leaving a residue that would be too low in value to be treated by any other means. In this case, only the portion under 40 mesh need be handled by flotation, and this at once cuts out a large portion of the tonnage, makes treatment costs lower, and appreciably reduces installation expense.

In addition there is a series of experiments that ought to be carried out on the slimes portion. A study of the series of articles on "Colloids in Ore Dressing"* shows that a differential system of flocculation and settling may possibly be carried out in such a way that perhaps the greater part, and sometimes practically all, of the valuable constituents can be segregated into a definite portion of the slimes. This will reduce the tonnage necessary to be treated by flotation and will naturally reduce installation expense as well as treatment cost. This question should be carefully investigated, since it is by no means impossible to carry out preliminary experiments towards a conclusion that will lead to a material simplification of the actual treatment.

* *Eng. and Min. Journal*, Feb. 5, 1916, and subsequent articles.

Actual Flotation Experiments.—In considering, however, the actual treatment by flotation itself, the points that have been enumerated will be the ones upon which a final decision will have to be based. In carrying out of such experiments, Hoover recommends a series, the first experiment of which is the crushing of ore to 60 mesh and testing in the slide machine at a ratio of dilution of 1 : 3, using a small quantity of acid and a frothing oil. This experiment is repeated with the same kind of ore at the same dilution but with about ten different variations of the oil, the recommendation being for the primary use of oleic acid. In each case the concentrate should be removed, weighed, and assayed. It is well known in flotation processes that a high-grade concentrate and high percentage of concentration cannot be procured at the same time. For this reason the usual practice is to first secure the highest possible percentage of concentration, removing from the ore the greatest possible quantity of the valuable minerals, and thereafter retreating the low-grade concentrate formed in order to eliminate as much as possible of the gangue and worthless material carried. This system is usually referred to as roughing, which is the first operation, and cleaning, which is the succeeding one. Cleaning, however, may be done any number of times, and in actual practice is often done three or four times and sometimes more. It is often possible, also, after having produced the first or rougher concentrate, to effect a selective flotation of the concentrates, by this means separating the constituents when two or more valuable minerals are to be saved. This is found particularly true in cases where zinc, lead, and perhaps some other minerals occur in combination, a good example of such ores being found in the Coeur d'Alene district of Northern Idaho.

In carrying out experiments one soon becomes accustomed to the behavior of froth and can tell at a glance whether or not good results are being obtained. By this means it is possible to save considerable time by eliminating the experiments that that are plainly not producing good results and this procedure will materially lessen the expense attached to testing.

Varying the Oil Factor.—After carrying out the first experiment as has been noted, another experiment should be started maintaining all the factors exactly the same except for the kind of oil, and in this way the best oil applicable to the ore is found

at first. Naturally, the selection of the oil is not the first in logical order of sequence, that place belonging to the stage of grinding required to secure good extraction of the ore. It is possible, however, to secure fairly good extraction from most ores that are ground to 60 mesh, and by determining definitely the best oil or oil combination to be used, or that which produces the best results, taking everything into consideration, at a grinding to 60 mesh, that experiment is pretty sure to provide an important basis for subsequent experiments. An oil that will produce the best results with the ore ground to 60 mesh will probably produce the best results with the same ore no matter to what mesh it is ground. That is not to say that the extraction percentage will be the same, because it naturally will vary with the grinding, but the fact remains that the oil best applicable to a certain ore at about 60 mesh will very likely be applicable and give best results no matter to what mesh the ore is ground. Having determined the kind, or combination, and quantity of oil to be used, this factor may be kept constant in all subsequent experiments. It is a good plan, however, after having fixed all other factors to go back to the oil again and determine whether or not any further variation will give better results.

In carrying out flotation experiments, as with any others, it is best to keep complete records and very full notes, even describing in the record book the appearance and physical action of the oils, pulp, froth, and every other detail that attracts attention.

Having determined the quantity and kind of oil to be used, the question of acid can be taken up, since that also is one that will not vary with the fineness of the ore. The use of acid is a factor that can almost always be determined roughly by forecasting, but experiments will have to be carried out to determine the quantity required. In a great many cases no acid at all is used and in other cases it is found to be required. The determination of this factor, however, is not difficult and may be carried out in a very short time. The same is true also with the dilution of the pulp. Usually it makes very little difference what the dilution may be, but it is important that that dilution should be constant throughout all work.

Effect of Grinding on the Tests.—After having determined the oil, acid, and dilution best adapted to the flotation treatment

of the ore under consideration, the next point to be determined is the degree of grinding that produces best results. In carrying out experiments of this kind, it is considerably better to take an ore that has been ground in practice, rather than one that is ground in the laboratory. Laboratory grinding gives a product that does not duplicate the work of stamps, rolls, tube mills, or whatever grinding machine is used in practice in the mill. If, however, laboratory grinding must be resorted to, the best way to perform it is to crush the ore in a great number of very short stages. To carry out work of this kind, a coarse ore should be put on the bucking board and broken down either with a muller or with a hammer until most of it is reduced to about ¼-in. size. The whole should then be screened, removing the product that has already reached the point to which grinding is to be carried in that particular experiment. If the first experiment is to be on 20-mesh product, a 20-mesh screen should be used at once to take out the rock that has already been ground that fine. Another crushing stage is then carried out, using breaking as far as possible instead of grinding, or rubbing, which may produce erroneous results in the subsequent experiments. The rubbing or grinding process is likely to change the angular state of the rock or mineral, a point that is of extreme importance in the flotation process. Ores that are ground in practice through rolls, stamps, tube mills, etc., are not subjected to this rubbing action and produce material that maintains its angular character to very high degree. Bucking the material on a bucking board has a tendency to round off the mineral grains, changing their shape and consequently their action under flotation conditions. This is a point that should not be overlooked, but which up to the present time has not been given a great deal of attention. Frequent screening should be carried out in order to avoid deformation or overgrinding of the rock particles. Of course the final grindings will probably have to be bucked, or rubbed, but while this does introduce a small factor of error, it is one that cannot be avoided and all one can do is to take the best possible care to have as little of that sort of manipulation as possible.

A series of tests on different screens varying between 20 and 100 and depending upon the ore to be treated and the conditions in general, will probably locate the best possible degree of sub-

division. Included in the grinding experiments should also be separation tests such as have already been mentioned, setting off the slimes to one side and the sands to another and determining whether or not treatment of different kinds could profitably be applied to the two products. In the whole field of ore testing, there is probably nothing so enlightening as screen classification, assay of the products and experimentation upon them by different metallurgical processes. It is a procedure upon which not nearly enough attention has been concentrated, but no other one point of study will throw so much light upon the character of an ore and its action under treatment than a thoroughly carried out and highly developed screen analysis, with metallurgical experiments upon the products.

Temperatures for Flotation Work.—Then, having determined the point to which grinding should be carried, another series of experiments should be carried on to find out the best temperature for flotation. In many cases heat is required, and in some cases to a high degree. In most instances, however, it will be found that by giving careful attention to details, maintaining dilution, and in general taking good care of the operation of the process, normal temperatures can be used without bad results. Following that, the series showing the amount of agitation to be used should be carried out, and in all of these series of tests, a wide range of variation should be attempted, thus securing as preliminary information a very thorough and valuable idea of what can be obtained in practical working.

In testing ores for flotation, it should be carefully borne in mind that experimental results, secured in the laboratory, will seldom or never reach the degree of perfection that can be obtained by large-scale mill practice. The flotation process is in this way a good deal like cyaniding and different from most other processes, by means of which careful work in the laboratory will secure better results than can usually be obtained in the plant. Both flotation and cyaniding, however, give their best results in large-scale work in the plant.

Examples of Testing Practice.—In order to illustrate the carrying out of testing experiments, a good example may be quoted from the publication by H. J. French.*

* "Flotation Test on Ores from Bisbee and Cobalt," *Columbia School of Mines Quarterly*, Nov., 1914.

In these tests the slide machine, already described, was used and a thorough description of the method followed was outlined. The machine was filled with water to a level slightly above the middle. If heat was required, it was obtained by repeatedly pouring boiling water into the machine until the walls became hot, and then it was filled with water near the desired temperature, which could thus be maintained. The ore was then agitated for a few seconds until thoroughly wetted. When the mixture reached the desired temperature, further heat being obtained from Bunsen burners if required, acid was added in the proper proportions, then the oil was added and the motor turned on, bringing it gradually but quickly to full speed. After the required agitation had been given, the agitator was stopped and the mixture allowed to settle for about a minute, thus allowing time for the froth to collect upon the surface of the water and for the gangue to settle. The upper part of the machine was then slid along the plane of contact, carrying with it the froth and part of the clean water above the plane of junction of the two parts. The process could be repeated on the tailings without the addition of more oil, but before further agitation, water should be added to just above the sliding plate. The tailings and remaining water were then withdrawn into a pan through the bottom spigot, allowed to settle, and the greater part of the water decanted. The tailings were dried, screened, mixed, sampled, and finally assayed or analyzed. The experiments were carried out about as has been noted in this description.

Experiments on the Bisbee Ore.—The Bisbee ore under treatment contains about 65.1% insoluble; 10.9% Fe; 0.9% CaO; 0.28% Al_2O_3; 6.04% Cu, and 12.7% S. After testing the ores in the slide machine, the tailings were assayed for sulphur, whence the percentage of extraction of the sulphides was computed. This is a very simple way of getting at it, and efficient in the case of these copper-sulphide ores. The accompanying tables show clearly the effect of the variation of the different items, and show what may be expected in experimenting upon an ore of the kind.

TABLE 1. EFFECT OF VARIATION IN AMOUNT OF OIL.

Pine-tar oil. 100 grams ore. 3-min. agitation. Room temperature. 35 drops H_2SO_4. 1500 c.c. water. Analyses on 1-gram sample.

Wt. of Oil, grams	Wt. of Froth, grams	Wt. of Tails, grams	Wt. of $BaSO_4$, grams	Wt. of S. in Tails from 100 grams Ore	% S in Tails	% S Extracted
0.5	3.5	97	0.8624	11.85	93.2	6.8
1.0	4.0	97	0.8610	11.81	93.0	7.0
1.3	4.5	97	0.7480	10.27	80.8	19.2
2.0	10.0	92	0.7290	10.00	78.7	21.3
2.5	11.5	91	0.6885	9.46	74.5	25.5
3.1	12.0	90	0.6308	8.66	68.3	31.7
4.0	13.0	91	0.6182	8.5	67.0	33.0
6.0	20.0	86	0.5329	7.3	57.5	42.5

TABLE 2. EFFECT OF VARIATION OF AMOUNT OF ACID.

Pine-tar oil, 3 grams. Ore, 50 grams. Agitation, 3 min. Room temperature. Analyses on 1-gram samples.

Drops of H_2SO_4 in 1500 c.c.	Wt. of Tails, grams	Wt. of $BaSO_4$, grams	Wt. of S. in Tails from 100 grams of Ore	% S in in Tails	% S Extracted
None	39.5	0.7320	10.10	80.0	20.0
50	29.9	0.5231	7.17	56.5	43.5
75	41.0	0.4927	6.75	53.1	46.9
100	38.0	0.4147	5.68	44.8	55.2
150	39.5	0.3952	5.43	42.8	57.2

TABLE 3. EFFECT OF VARIATION IN TIME OF AGITATION.

Pine-tar oil, 3 grams. Ore, 50 grams. Room temperature. 100 drops acid in 1500 c.c. of water (= 0.3%). Anaylses on 1-gram samples.

Time of Agitation, Min.	Wt. of Froth, grams	Wt. of Tails, grams	Wt. of $BaSO_4$, grams	Wt. of S in Tails from 100 gm. Ore	% S in Tails	% S Extracted
3	19	37.0	——	——	——	——
6	8	48.0	0.620	8.5	67	33
10	20	36.0	0.404	5.53	43.5	56.5
15	16	39.0	0.804	11.0	86.0	14
20	12	44.0	0.503	6.9	54.5	45.5

TABLE 4. EFFECT OF VARIATION IN TEMPERATURE.

Pine-tar oil, 6 grams. Acid, 5 grams. Ore, 50 grams. Agitation in two 5-min. periods, skimming after each period. Analyses on 1-gram samples.

Temp. °C.	Wt. of Froth, grams	Wt. of Tails, grams	Wt. of $BaSO_4$, grams	Wt. of S in Tails from 100 gm. Ore	% S in Tails	% S Extracted
25	20	36	0.850	12.0	92	8
40	29	27	0.535	7.3	57	43
50	22	34	0.640	8.8	69	31
65	14	42	0.450	6.2	48.6	57.4

TABLE 5. SCREEN ANALYSIS OF BISBEE ORE.

Screen opening, in.	Mesh Approximate	Wt. per 100 grams of Ore	Wt. of $BaSO_4$ from 1-gram Samples	Equivalent Sulphur %
0.0116	48	4.0	——	——
0.0082	65	13.5	2.1038	28.9
0.0058	100	21.8	1.2003	17.04
0.0041	150	14.7	1.0022	14.05
0.0029	200	14.0	0.9175	12.60
Below 0.0029	— 200	32.0	0.7124	9.80

TABLE 6. EFFECT OF VARIATION IN SIZE OF ORE.

Ore, 50 grams. Acid, 0.3%. Pine-tar oil, 6 grams. Temperature, 65° C. Two 5-min. agitation periods. Analyses on 1-gram samples.

Mesh	Wt. of Froth, grams	Wt. of Tails, grams	Wt. of $BaSO_4$	Sulphur in Tails, %	Sulphur Extracted, %
48- 65	12	44	1.1080	57.3	47.7
65-100	28	28	0.3396	27.3	72.7
100-150	26	30	0.1294	10.3	89.7
150-200	19	37	0.3496	38.0	62.0
Below 200	19	37	0.2500	35.0	65.0

TABLE 7. EFFECT OF VARIOUS OILS ON COBALT ORE.

Ore, 100 grams. Water, 1500 c.c. Agitation, 1 min. Room temperature. Oil, 8 drops. Acid, I gram.

Oil	Wt. of Tails, grams	Wt. of Froth, grams	Oz. Ag per Ton Tails
Pine-tar	97	3.0	9.6
Fish	98.5	3.0	12.46
Sperm	98	2.0	12.94
Corn	84.0	16.0	13.36
Whale	98.0	2.0	13.8
Cylinder	(a)	....	.....
Rapeseed.....	90.0	10.0	10.87
Lard	90.0	10.0	13.13
Cottonseed	93.0	7.0	12.66

(a) No froth.

TABLE 8. EFFECT OF VARIATION IN AMOUNT OF OIL.

Ore, 100 grams. Water, 1500 c.c. Acid, 1.5 grams. Room temperature. Agitation period, 2 min. Pine-tar oil.

Oil, grams	Wt. of Froth, grams	Wt. of Tails, grams	Ag in Tails, oz. per ton.	% Ag remaining in Tails.	% Ag Extracted
0.3	7.0	93.5	11.44	84.0	16
0.6	12.0	89.0	10.20	75.0	25
1.0	15.0	84.5	8.25	60.6	39.4
1.3	11.5	90.0	8.28	60.8	39.2
1.6	15.0	87.0	8.68	63.8	36.2
2.3	16.0	87.5	6.66	49.0	51.0
3.0	25.0	78.0	.....	....	....
3.3	22.0	81.0	6.45	47.5	52.5

The Cobalt Ores.—A series of tests were also carried out on characteristic ores from Cobalt, the particular samples being from the Coniagas Mining Co. The ore contained about 13 oz. of silver per ton, mainly in the form of pyrargyrite, proustite, argentite, dyscrasite, and native silver. The procedure was about the same as for the Bisbee ores, but in this case the tailings were analyzed for silver. The accompanying tables show the results obtained in the work upon the Coniagas ores. This work is an example of good procedure and enlightening results

acquired through careful experimentation. It must be borne in mind, however, that they were carried out a long time ago, in comparison with the rate of progress of the flotation process. If done at the present time, further investigations would undoubtedly be carried out, since a great deal more has been learned about flotation and its requirements in the last year or two. It is true, nevertheless, that this work is a type of good experimental flotation procedure, and would give a vast amount of information about the action of the ores even at the present time. In fact it might be quite sufficient to show the best that could be done with the ores.

Experimental Flotation Machines.—The slide machine has been very largely used for experimental flotation work for a long time, but, due to the convenience of the more modern experimental machines and to the fact that they produce results more nearly comparable with those obtained in plant practice, it has gone almost altogether out of use. The small machines designed on the same lines as the large apparatus used in the plant have almost entirely taken its place. Many of these machines are to be had on the open market at the present time, or they may be put together rather inexpensively at the plants where experiments are to be carried out. As has been said, they come nearer duplicating plant results than the slide machine does, since they actually agitate the ore in a practical way to produce the froth, and the froth then overflows into some convenient receptacle, just as it does in practice.

In the operation of any of these machines that are designed to make an oil froth, enough clear water is run into the machine to show in the spitzkasten and then the motor is started. The ore charge is then added and a thorough mixture secured. At this point the machine may be stopped and other ingredients added if required, but if not, water is added until the froth begins to overflow from the lip. It is usually better to secure thorough agitation before the froth is allowed to overflow, and when it does overflow, it may be allowed to do so of its own accord or it may be assisted by skimming with a paddle or some other convenient utensil. As a matter of fact some of the practical machines use skimming devices to assist in the removal of the froth as it is formed. The duration of agitation in the ordinary test is about 5 min., but this is a variable quantity and

cannot be taken as even approximately fixed, because some ores require considerably more, while others will produce their maximum of froth in a very short time.

The Callow Testing Method.—In carrying out tests for flotation by the Callow pneumatic process, it is best to do so in a machine of the same type. Miniature Callow machines are supplied for this purpose, and may be had of appropriate size to carry out experimental work. They are usually provided

FIG. 21.—A CALLOW TESTING UNIT.

with a primary mixer—a Pachuca tank—such as has been used in practice as an integral part of the process. The Pachuca tank is exactly like those used in the cyanide process for agitating slimes and consists of a long, cylindrical cone-bottomed tank having a central air column. Agitation is by introduction of air under low pressure to this central column, making the pulp in the column lighter, on account of which it rises, the mass of pulp in the rest of the tank falling in proportion. The Callow test machine is really no more than a miniature of the regular installation. The air is subdivided into fine particles by a pas-

sage through the canvas filter bottom and passes up through the pulp, raising the oiled sulphides that become attached to the air bubbles. In carrying out tests with this machine, there is nothing that has to be changed, as compared with testing in other devices, except the operation of the machine itself. A clear understanding of the Callow flotation machine as used in mills following the process is all that is required to successfully carry out small-scale experiments with it. The procedure of testing does not change at all, the only difference being in the machine manipulation.

In carrying out this process the mixture of ore, water, oil, and other reagents is fed into the suction of the sand pump or into the top of the Pachuca tank after air has been started into the various machines. Sometimes the Pachuca tank is omitted, provided proper mixture can be obtained before the pulp is put into the frothing machine. In practice it has been found quite possible to leave the Pachuca tank out of operation, thorough mixing being secured by the pumping and general agitation as the pulp passes through the machinery preceding the flotation plant. The overflow from the Pachuca tank, when it is used, into the rougher cell accumulates until a good froth comes up and nearly overflows. Then the tailings discharge-valve in the rougher is gradually opened and the froth allowed to overflow from the cell into the cleaner cell. It is considered best practice to get most of the charge circulating before a great deal of the froth is allowed to overflow, the overflow of froth being controlled by the main air valves leading to each unit. Once adjusted, these valves leading to the individual air boxes in the bottom of the machine should never be disturbed, and all control of air supply should be at the valves in the main pipe. When everything has been adjusted to smooth operation, the air pressure in the cleaner can be increased until concentrate froth is overflowing into the vacuum filter, a small miniature one being installed at the tail end of the flotation machine. This filter may be of the simplest kind, even an ordinary glass funnel with filter paper set in the laboratory suction pump will answer the purpose satisfactorily. Any settled material in the flotation cells should be stirred up, which can be done with a small stream of water, or with a glass rod or wooden stick.

All the foregoing description has applied to those flotation

processes which use oil, and have froths formed by mechanical or air agitation of the pulp. The other processes—film flotation —that are in practical use include the Macquisten and the Wood processes. These are the principal ones and, although there are some others—notably the Potter-Delprat—actual large-scale practice is practically confined to the Macquisten and Wood processes. The Wood machine can be built in miniature, as is the case with other machines of the kind that have been used to carry out experimental work. The method of operating is the same as that of a full sized machine. The experimental device is about as shown in Fig. 20, on page 100. As in this process the surface tension is the only factor affecting results, the work has to be carried out with extreme care, just as it does in practical work at the plant.

As to the Macquisten process, a single tube of the ordinary commercial size is usually used, and is plenty small enough to secure results on an experimental scale. No further explanation of that machine is necessary.

The Potter-Delprat Method.—The explanation of testing ores by the Potter-Delprat process is best given by Ralston and Allen.* An illustrative test is described by them. Tubes containing 3% sulphuric acid, or acid sulphate solutions and a little sulphide ore are warmed nearly to boiling temperature. Bubbles of CO_2 attach themselves to the sulphides, travel to the surface of the solution, discharge into the air, and drop the sulphides into the pocket on the underside of the tube, made for the purpose. In another test a 200-c.c. beaker is used with 100 c.c. of 3% sulphuric acid, and brought to nearly boiling temperature. The ore when introduced into this yields a froth composed of sulphides supported by bubbles of CO_2. In case the ore is deficient in carbonate, an addition of as much as 3% of calcite or siderite is made. The froth is skimmed with a spoon as soon as it forms. A great deal of mineral is partly lifted, but never reaches the surface. Consequently extractions are low, although the grade of the concentrate obtained is usually very good. For practical purposes, a test of this kind is not of much value, and a better test machine is a small unit shown in Fig. 22. The acid should be allowed to run down through a section of garden hose

* "Testing Ores for the Flotation Process," *Min. and Sci. Press*, Jan. 1, 1916, the basis of their work being taken from Hoover's original book.

to within an inch of the surface of the ore. The ore should be kept stirred with a wooden paddle so that the bubbles of CO_2 generated by the action of the acid can lift the sulphides out of the body of the pulp. The froth formed should be skimmed with the paddle as fast as made, then filtered, dried, weighed, and analyzed. Not many ores yield good extractions by this treatment, and the slime gives particularly poor extractions. Fines and Wilfley-table middlings are better adapted, and the presence of siderite in the pulp is desirable, as it reacts slowly with dilute acid. From 1 to 3% sulphuric acid is best in testing, and ½ to 1½% solutions on the large scale will give about the same results. The temperature of the pulp should be maintained at 70° C. by use of a steam jet. Five to ten lb. of ore per test is necessary. The extractions obtained are always lower than in full-size units. While oil is not necessary in this process, it will greatly assist in the flotation, and the addition of a small amount is often of much assistance in test work.

Tests Using Coal Tar.—An illustration of the method of making flotation tests, as carried out in some cases, is given by William A. Mueller.* In giving this description, which was primarily for the purpose of determining the value of coal tar as a flotation agent, Mueller describes the usual small two-compartment machine which was used. One compartment comprised agitation mechanism, which agitated pulp by means of a stirrer. This agitation compartment was connected with the other compartment—the spitzkasten—by a narrow slit near the bottom and a large opening near the middle. This enabled the aerated pulp to flow from the agitation into the next compartment, where no agitation took place. The froth rose to the surface and was skimmed off with a spoon or spatula. The test was not complete until no more mineral-bearing froth was formed. The capacity of the machine was about 2,000 c.c. In all respects this machine was just about the same as the others which have been described heretofore.

For each experiment the time of flotation was noted, this being the period from the beginning of flotation until no more mineral-bearing froth formed in the machine. In all experiments the first product formed was called concentrate, and when this no longer came off, turpentine was added and the next product was

* "Use of Coal Tar in Flotation," *Eng. and Min. Journal*, Oct. 9, 1915.

called middling. The system corresponded to that followed when the ore goes to the Mineral Separation type of machine, where the concentrates are formed in the first two compartments, then turpentine is added, and the latter products taken off as middlings and retreated, either in the same machine or in a similar one.

The Elmore Processes.—Other processes of flotation that have not been described here in the experimental way, are the two

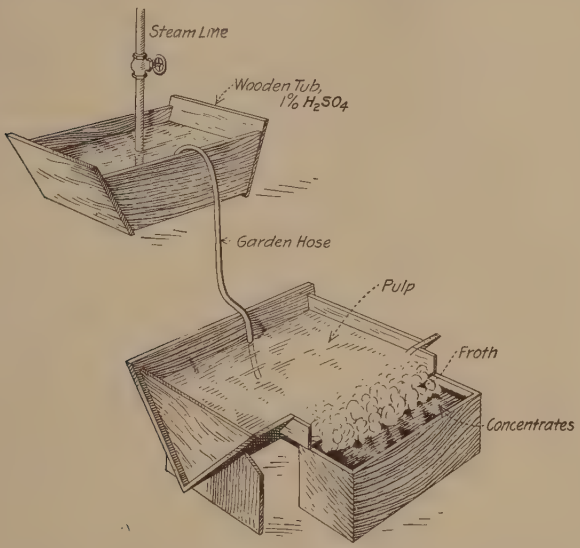


FIG. 22.—A TEST PLANT FOR THE POTTER-DELPRAT PROCESS.

Elmore systems—the bulk-oil system and the vacuum process. Neither of these processes is used to any great extent in this country at the present time, so that there is no recent addition to the original literature as to their experimental methods. The description given herewith is taken from Hoover's original book. In that description he shows that the old Elmore process may be tried in a glass jar of about 1,000 c.c. capacity. What is known as a Mason fruit jar with a screw top is the best apparatus for this trial. Into the jar 300 c.c. of water is placed, to-

gether with 100 grams of sulphide ore, and the whole stirred to make a uniform pulp. Then ½ c.c. of strong sulphuric acid and 200 c.c. of thick oil are added, the oil being a heavy, viscous oil, such as the thick, tarry residue of petroleum, or perhaps a cylinder oil. Screw on the top of the jar, turn it end for end about twenty times, and then set aside to settle for a few moments. The contents of the jar will settle into layers, and at the bottom a layer of sand mixed with some sulphides will be seen. Next above this will be a layer of muddy water, and above that again will be a layer of oil containing most of the sulphides, the amount depending on the success of the maneuver, together with some gangue. The oil layer may be removed by adding more water carefully beneath the oil through a tube, and after the oil and sulphides have been removed, the sulphides can be separated from the oil by heat and gentle agitation, when they will settle to the bottom. This is, in other words, simply reducing the viscosity of the oil so that the sulphides may be dropped through it.

The new vacuum process is more difficult to test in a small way so as to produce satisfactory results. Probably the best method is as follows: Take a large-mouthed 300 c.c. bottle, and fit a stopper with a tube to be attached to a laboratory suction pump. Put into the bottom 30 gr. of sulphide ore, 100 gr. of water, 1/5 c.c. of Texas or California fuel oil, and 1/5 c.c. of sulphuric acid. Stir this with a glass rod until the uniform pulp is produced, but do not beat any air into the pulp. Place a stopper in the bottle and attach to the suction pump. Stir the pulp and gently shake the bottle to keep the ore stirred up a little. As the vacuum is produced, the sulphides should begin to rise to the surface and form a layer of froth. While this process has not been applied to any great extent in this country, at least to my knowledge, it has been applied with successful results in some foreign mills. The Dolcoath tin mines of Cornwall, some mines of the Zinc Corporation, and some of the Norwegian iron mines have used the process successfully.

Recording Test Work.—The matter of record for test work has already been referred to, but a rather good form of recording data is given by Whittaker and Belchic.* In pointing out

* "A Form for the Classification of Flotation Data," *Met. and Chem. Eng.*, Jan. 1, 1916.

Flotation Experiments

Number of Sample b Date May - 1915

Assay { Zinc = 5.17 %
Lead = trace } Number of Experiment 12

SCREEN ANALYSIS

SCREEN			WEIGHTS			ASSAYS		
	Mesh	Opening Inches	Sample Weights Grams	Per Cent.	Per Cent. Accumulative Weights	% Zinc		
All Pass.	35	.0164	—	—	—	—	—	
Retained	48	.0116	2.0	0.417	0.417			
"	65	.0082	3.0	0.625	1.042	2.54		
"	100	.0058	9.0	1.875	2.915			
"	150	.0041	34.0	7.08	9.995	3.8		
"	200	.0029	85.0	17.70	27.695	4.58		
Pass thru	200	.0029	347.0	72.30	—	5.56		
Totals			480.0	100.0				

To show the effect of variation in quantity Pine Oil

CHARGE		Variable grams	DERIVED DATA			
			Froth	Assay of Con.		% Ext
				Zn	Pb	
Ore, grams	400.					
Water, "	1200.	0.5	29.0	53.2	—	74.6
Acid, " H_2SO_4	2.0	1.0	38.0	43.1	—	79.2
Oil, "	Variable	1.5	37.0	42.4	—	75.8
Temp. in °C.	65	2.0	51.0	28.6	—	70.0
Speed, RPM.	2000					
Time, minutes	7					

EFFICIENCY CURVE

Efficiency of Pine Oil in terms of frothy assay and extraction.

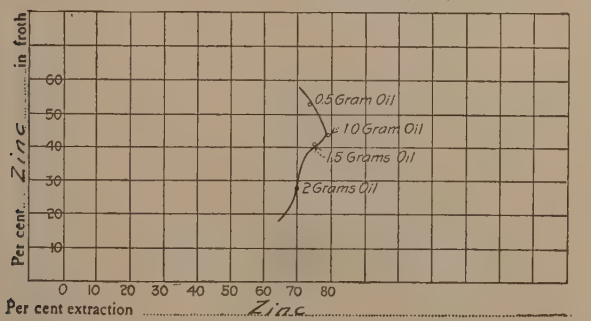


FIG. 23.—A RECORDING FORM FOR FLOTATION EXPERIMENTS.

the use of some recording form, the authors call attention to the increasing importance of flotation as a method for ore concentration and metal conservation, which is illustrated by the fact that many private corporations, as well as university laboratories, are engaged in investigating the process. Most of these investigators have as their object the defining of the conditions necessary for successful flotation when applied to particular material, while others are engaged in purely theoretical work, looking toward an explanation of the various phenomena upon which flotation is based. Whatever the object sought, the investigation, if prosecuted to any extent, will result in the accumulation of a large amount of minute data, which unless arranged in such a way as to allow of ready comparison and correlation, may soon become a mass of unwieldy material, difficult of clear interpretation.

In order to compile in a condensed arrangement the results obtained in the laboratory and thus allow quick and easy comparison and correlation, the form illustrated here was evolved and printed in quantity. With this arrangement the investigator has before him on one sheet (1) the screen analysis, (2) the assays, (3) the charge used, (4) the derived data, and (5) the plotted efficiency of the frothing agent. The same form may be used also when the essential other flotation factors are being investigated, such as the variations of temperature, duration and speed of agitation, quantity of acid, etc. This condensed scheme has worked so satisfactorily that it was thought that its publication might be helpful to those who are beginning investigations on flotation and possibly to those already launched upon the subject. The work was done at the laboratory of the University of Kansas, at Lawrence, Kan.

In a review of what has already been brought out in regard to flotation testing, it may be as well to direct further attention to the fact that the results secured in the laboratory cannot be as satisfactory as results secured by plant work on the large scale. The reasons depend principally upon the smallness of the machine, of the very shallow layer of froth that is often formed under such conditions. Laboratory operations, also, seem inevitably to call for greater quantities of oil, acid, and whatever other chemicals are used to secure results. It seems impossible to duplicate the very small quantities, of oil for

instance, used in practical work on the plant, in laboratory experiments.

Of the machines that have been described, and the methods accompanying them, there can be no recommendation in general as to which is the best. In this country the oil flotation—with or without acid, but more generally without it—holds the greatest amount of favorable consideration. The surface-film methods, such as the Macquisten and the Wood, have been tried and are really being used in practice. They give good results under some circumstances, but in other cases the oil-froth processes seem to be better. It is believed in general that the latter processes are easier to install, apply, and manage, since they seem to require less delicate regulation than the film methods. As to such processes as the Elmore, both old and new systems, the Potter-Delprat, and the others already mentioned, their application is exceedingly limited, at least in the United States, and one may say in North America in general.

Floating Oxidized Ores.—Considerable work on the flotation of oxidized ores has been done by the Salt Lake Station of the Bureau of Mines in coöperation with the metallurgical department of the University of Utah. An article on the subject has been written by O. C. Ralston and Glenn L. Allen, and issued by the Bureau of Mines. Attention is called to the fact that most of the experimental work has been done on oxidized ores of lead, because little success has been had with zinc ores, and many others are engaged in working on copper ores.

The successful flotation of oxidized mineral depends, in the opinion of the operators, upon its preliminary sulphidizing, in order to convert at least the surface of the mineral particles to sulphide form. This step is then followed by flotation just as is practiced on the natural sulphide ores. The sulphidizing methods investigated have been that by the use of hydrogen sulphide on either dry or wet ore; by the use of various sulphide solutions and sulpho compounds of sodium; by the use of solutions of the various sulphides and sulpho compounds of calcium; by the use of sulphur vapor; by the use of a sulphureted oil, and with colloidal sulphur. It was found that some of these methods formed a sulphide film on the surface of the particles of such minerals as lead carbonate or copper carbonate, whereas in

other cases the mineral particles are sulphidized all the way through.

The methods have been tried on a large number of lead-carbonate ores. Some contain silver and some lead as the principal metal. Many ores have been successfully concentrated, while others refused to yield to flotation concentration. In general, a high alumina content (acid soluble) seems to prevent sulphidizing and flotation. It was found that the best method of applying hydrogen-sulphide gas to dry powdered ore was in a tumbling barrel with a gas inlet in the end. Sulphidizing in a glass bottle showed that the ore blackened quickly after the application of the gas. On attempting to float the lead sulphide as soon as it was blackened, it was found that a low extraction was obtained and also low-grade concentrates unless the pulp was previously acidified with sulphuric acid. By acidifying the pulp, cleaner concentrates were secured, but extractions of lead still remained low. Only by prolonged treatment with hydrogen sulphide gas could the extraction of lead be raised to commercial grade. With a number of ores 8 hr. treatment gave an extraction of over 80% of the lead.

Hydrogen sulphide was considered because it can be cheaply generated. With iron matte available at $5 to $10 per ton and sulphuric acid at about the same price, the cost of the hydrogen sulphide resulting, including all operations, is between $30 and $50 per ton. If this gas in combining with the metal in the ore produces only a superficial film of sulphide, it might be possible to make a ton of gas sulphidize many tons of ore. It was found, however, that the gas attacked the ore with such avidity that by the time the latter was sulphidized sufficiently to permit of good extraction by flotation, it had been sulphidized all through, and practically a chemical equivalent of hydrogen sulphide to the lead in the ore had been absorbed. Application of hydrogen sulphide to the ground ore suspended in water does not seem to be subject to the same difficulty. Filming of the particles seems to take place, and the extractions after a short treatment with the gas are satisfactory.

The best results on lead-carbonate ores were obtained when sodium sulphide was used for the sulphidizing agent. Sodium sulphide has to be introduced in solution and seems to cause true filming. The sulphides of sodium considered commercially ap-

plicable are the normal sulphides, Na_2S; sodium polysulphides, Na_2S_4, and Na_2S_5, and the sulphhydrate of sodium, NaSH. The last seems to be quite effective. The normal sulphide is almost as effective, while the polysulphides are the least active. Different ores require from 10 min. to 24 hr. of contact with the sulphide solutions used, depending on the characters of the ore and the substance of the solution. Sodium sulphide varying from 10 to 20 lb. per ton of ore is usually sufficient and should be applied to pulp containing about one ton of water per ton of ore, in order that the solution may be as strong as possible during the sulphidizing stage of the process. After a good black color has developed and the color has ceased to increase in blackness, the pulp is diluted with water to 3:1 or 4:1, and floated. The market for sodium sulphide is limited, and it should be obtainable for less than 2c. per lb., making a process economical enough for commercial purposes.

The polysulphide of calcium, obtained by boiling powdered sulphur with slacked lime, is satisfactory for ores that yield easily to sulphidizing, but is sluggish in action as compared with the sulphides of sodium. Sulphidizing with sulphur vapor has been tried with little success, for the reason that it must be applied at a temperature above the boiling point of sulphur in order to prevent condensation. This means that a temperature of over 445° C. must be reached. The use of a sulphureted flotation oil, in which loosely combined sulphur is available for combination with carbonates of lead or other metals, and the rest of the oil is then available for oiling the artificial sulphide, has given but little encouragement. Colloidal sulphur, mentioned as a possible method of sulphidizing, does not seem to combine with lead carbonate at all. It floats as a white lining of air bubbles in the flotation machine and brings up very little lead with it.

The Course of the Precious Metals.—Usually the precious metals contained in a lead-carbonate ore accompany the lead. It has been noticed that the silver extraction will lag behind the lead extraction when the ore is sulphidized with sodium sulphide and that the reverse has usually been true when hydrogen sulphide was used. The importance of sulphidizing flotation is due to the fact that there are many deposits of lead-carbonate ore in the Western States, and many of these ores

have been milled with varying success. Frequently lead carbonates can be satisfactorily concentrated by gravity methods, but often it is found that particles of lead carbonates go into the slime and are lost. Tailings containing 5 to 10% of lead are common, and the object of the investigation was to determine whether sulphidizing flotation could be applied to the treatment of these deposits, and also to prevent the waste that now takes place when they are treated by gravity concentration. It would also, if successful, render amenable to treatment carbonate ores that are too low in grade to be handled by present methods. A flotation plant to apply sulphidizing flotation to an ore containing lead, silver, and gold is being constructed by the Prince Consolidated Mining Co., at Pioche, Nev., for the treatment of two tailings dumps from former pan amalgamation and cyanide operations in that vicinity. It was expected that the plant would be in operation by July 1 of this year.

Tests on Copper and Zinc Ores.—A few tests were made on oxidized copper ores, and hydrogen sulphide seems to be the best medium for sulphidizing these particles. When applied to the dry ore, the sulphur permeates the particles as it did in the lead ores. Applied to the wet pulp, the hydrogen sulphide seems to cause true filming. Usually black concentrates are yielded, but J. M. Callow, of the General Engineering Co., announced that that company has been able to reduce the amount of sulphur used to a point where the froth is green with slightly coated malachite. He has used as little as ½ lb. of sulphur per ton of ore, and that is giving good extraction in the plant of the Magma Copper Co., at Magma, Ariz., where his company has put in a successful installation. Sodium sulphide has been tested by a number of large companies where some little oxidized copper occurs in the sulphide ores. In this case only 2 or 3 lb. of sodium sulphide per ton of ore is used. This is easily added to the machines during flotation or to the mixing tanks before flotation. The experience is that if some little time of preliminary contact is allowed before flotation is attempted, better sulphidizing of the material will result. Calcium polysulphide has been used for some time in a number of large copper mills with indifferent success and seems to be detrimental in some instances. On some of the ores tested fair results were obtained if the calcium polysulphide was allowed to act until the ore had become

well blackened. Sulphur vapor is also said to give good results in some cases. Sulphureted oils are being used also, but considerable secrecy is observed as to technical details of the work. Colloidal sulphur does not assist, so far as is known, in the flotation of oxidized copper. Attempts to float the natural sulphides along with sulphidized minerals have usually failed, since the sulphidizing agents cause trouble with the flotation of natural sulphides. At one plant this difficulty has been solved, although the details are not available.

Attempts to float oxidized particles of zinc from ores, both before and after sulphidizing by most of the methods that have been mentioned, have met with no success whatever in the laboratory experiments carried out. Possibly the fact that most of the carbonate ores of zinc contain important amounts of the silicate may be one of the reasons for the lack of success with this work.

In testing according to the directions and indications that have been given here, almost exclusive attention has been given to the base metal ores, and little has been said about gold and silver. As a matter of fact, there has been little public admission that the process has been applied to any such ores, but cases are privately known where free gold has been successfully recovered by flotation, and there are also cases that definitely show that silver sulphides, such as occur largely in Mexico, may easily be recovered by flotation. The indications are strongly in favor, in the latter case, of separating the ore into sands and slimes, concentrating the former by gravity methods, and the latter by flotation methods. When making flotation experiments upon ore of this kind, this fact should be borne in mind.

CHAPTER VII

TESTING AT THE ANACONDA MILL

As a practical example of test work carefully carried out, nothing better could be cited than that performed at the Washoe plant of the Anaconda Copper Mining Co. The procedure has been described by Frederick Laist and Albert E. Wiggin in the Bulletin of the American Institute of Mining Engineers, March, 1916. The value of this work is so great that I have considered it well worth a special chapter in this book, so that a review of the work done will be given here.

Early in 1914 it was decided to test, on a large scale, the treatment by flotation of Anaconda slime and mill tailing. For this purpose a standard type Minerals Separation machine was installed at the Washoe Reduction Works during May and June, 1914. This was followed by the installation of a full-size Callow pneumatic plant. In addition to the tests made in the standard-type Minerals Separation machine some tests were made using a Minerals Separation machine of the sub-aeration type.

During the series of experiments a large variety of oils was tested. Experiments were also conducted using both round-table feed and tailing to determine whether it would be better to displace the round tables by flotation for the treatment of the slime, or to supplement the round tables by flotation of the round-table tailing. A series of tests was also made on the treatment of the mill tailing by grinding followed by flotation to determine the relative merits of flotation and leaching for the treatment of this product. In addition, flotation tests were made on mixtures of mill tailing and slime.

The round-table feed referred to above is the total slime from the mill. It contains about 35% colloidal solids and approximately 90 to 95% of the total solids will pass through 200 mesh (0.067 mm.). It assays from 2.3 to 2.6% Cu. The mill tailing referred to above is the total discard from the mill, exclusive of the slime. It is all finer than 2 mm. and about 90 to 95% will remain on 0.25 mm. It assays about 0.60% Cu.

Preliminary Tests.—A series of tests was first carried out to determine roughly the best conditions for flotation, using the standard Minerals Separation machine and treating round-table feed. The following reagents were tested either alone, or in combinations: Turpentine, crude oil, cresylic acid, stove oil, tar oil, Carolina oil of tar, argols, sludge acid, fuel oil, wood creosote, and sulphuric acid. In some of these tests sulphuric acid was used and in others it was omitted. The effect of the temperature of the pulp upon the flotation results was tested by heating to various temperatures. As these tests were merely preliminary no record was kept of the amount of reagents used. It was conclusively proved, however, that the best combination of reagents was sludge acid, wood creosote, stove oil, and sulphuric acid. Of all the reagents tested, these happened to be the cheapest. It was also proved that the addition of sulphuric acid to the pulp was of decided advantage in the treatment of slime. In two successive tests in which sludge acid, wood creosote, and stove oil were used, the tailing assayed 1.25% Cu when no acid was used and 0.3% Cu when acid was used. Since these tests were made we have omitted the use of stove oil.

This machine had 16 agitator compartments, each 2 ft. square, and 14 spitzkastens, and was of the standard Minerals Separation design. This machine is known as M. S. Machine No. 1. The agitators were of the standard Minerals Separation type, the impellers being 18 in. in diameter and the agitators making 265 r.p.m. This gave the impellers a peripheral speed of 1,245 ft. per minute. The machine required 45 to 55 hp., including motor and belt transmission loss, when operating under a full load of slime pulp. The first products to be tested were the round-table feed and tailing.

(a) Round-Table Feed. Normal Tonnage (60 Tons). Pulp Heated to 70° to 90° F.—The reagents used in Periods 2 and 11 were kerosene sludge acid (M. S. 37), crude wood creosote (M. S. 33), stove oil (M. S. 8), and sulphuric acid.

Period 2, in which the pulp was heated to an average temperature of 89° F., gave a tailing running 0.23% Cu, with a fair grade of concentrate. Period 11, in which more creosote was used, all other conditions remaining as in Period 2, gave a tailing assaying 0.27% Cu, with a slightly better grade of concentrate.

It should be noted, however, that it is not characteristic of creosote to give a clean concentrate, it being rather a good "tailing" oil and the slight increase in the grade of concentrate should not be attributed to the increase in the amount of creosote used, but rather to a difference in operation of the machine. Period 20, in which Pensacola creosote was used, shows an average tailing of 0.33% Cu, and a very clean concentrate. It should be noted that considerably less creosote was used than in Period 11.

(b) Round-Table Feed. Pulp Not Heated.—During Periods 3 and 10, the pulp was not heated, but treated at a temperature of 50° F. The tests were made during the summer months; it should be noted that during the winter months the temperature of the pulp would be about 40° F., with a minimum of about 35° F. During Period 3, the tailing assayed 0.32% Cu, with a low-grade concentrate, and during Period 10 the tailing averaged 0.42% Cu, with a higher concentrate.

(c) Round-Table Feed. Pulp Heated to 125° F.—Heating the pulp to a temperature of 125° F. (Period 4) gave a tailing of 0.21% Cu with a fair grade of concentrate. As Period 2, in which the pulp was heated to 90° F., gave a 0.23% Cu tailing it is evident that heating beyond 90° F. does not pay. In fact, a careful study of the tabulated results would indicate that it does not pay to heat above about 75° F. The cost of heating the slime pulp for flotation is about 1c. per ton of dry slime for every 2½° F.

(d) Round-Table Tailing. Pulp Not Heated.—The treatment of the round-table tailing, after dewatering to a density of 11.5% solids (Period 5), gave a tailing of 0.25% Cu with a low-grade concentrate. It was though that possibly the net recovery would be sufficiently more to justify the retention of the round tables if the tailing from the round table instead of the feed to the round table were treated by flotation.

(e) Round-Table Tailing. Pulp Heated to 106° F.—It is evident from the result of this test (Period 6) that the heating in the case of the round-table tailing was of no benefit.

(f) Round-Table Feed. High Density of Pulp. Pulp Heated to 96° F.—The density of the round-table feed was increased to 22.5% solids by a second dewatering (Period 7). As had been expected, the increase in density considerably decreased

the oil consumption without decreasing the recovery of copper, and of course would also decrease the expense of heating the pulp.

(g) Round-Table Feed. High Density of Pulp. High Tonnage (105 Tons). Pulp Heated to 96° F.—It was thought that by increasing the density of the pulp it might be possible to treat the same volume of pulp per machine unit as with the lower density, and in that way increase the tonnage of solids treated. The tests under Period 8, however, show that any considerable increase in the amount of feed to the Minerals Separation No. 1 machine over 60 tons results in a decided increase in the tailing loss.

(h) Round-Table Feed. High Density of Pulp. High Tonnage. Pulp Not Heated.—The value of heating the pulp in the case of high density feed pulp is brought out by this test (Period 9), where the tailing jumped to 1.28% Cu with the absence of heat.

(i) Round-Table Tailing. High Pulp Density. Pulp Heated to 70° F.—This test (Period 12) gave a tailing of 0.45% Cu, and a low-grade concentrate.

(j) Round-Table Tailing. Medium Pulp Density. Pulp Heated to 80° F.—This test (Period 13A) gave a good tailing assaying but 0.20% Cu. This would seem to indicate that too high a pulp density in the treatment of the round-table tailing is a decided disadvantage.

(k) Round-Table Tailing. Medium Pulp Density. Pulp Heated to 80° F.—In this test (Period 13B) no acid was used, and as a result the tailing went up to 0.96% Cu. Note also the low silver content of the concentrate.

(l) Round-Table Tailing. Low Pulp Density. Pulp Heated to 70° to 80° F.—In (Periods 14A, B, C, and D) the round-table tailing pulp was not dewatered at all, but treated directly at a density of about 6% solids. The tailing was good, ranging from 0.16% Cu to 0.22% Cu, for the four tests. During Period 4B, crude turpentine was used in place of creosote; during Period 14C, crude wood creosote was used, and during Period 14D, crude wood creosote was used. All of these oils gave satisfactory results. The increased amounts of these oils used during these tests were undoubtedly due to the low density of the pulp, and to the low tonnage treated.

(m) Round-Table Feed. Low Pulp Density. Low Tonnage (40 to 50 Tons). Pulp Heated to from 70° to 80° F.—It was thought that the low tailing produced during Periods 14A, B, C, and D was due to the low tonnage treated, and possibly to the low pulp density, as well as to the fact that round-table tailing was being treated. Accordingly, the tests under Periods 15A, B, C, D, and E were made and in these a low tonnage of round-table feed was treated with a low pulp density. These tests gave fully as good results from the recovery standpoint in a considerably better grade of concentrate as those made on the round-table tailing under similar conditions.

During Period 15A, wood creosote was used. During Period 15D, no creosote was used and the tailing assay increased from about 0.20% Cu to 0.32% Cu. During Period 15E, some other creosote was used, but gave a high tailing—0.42% Cu. During Period 15B, tar creosote from a gas works was used with apparently good results, although the test was too short to be taken as conclusive proof of the value of this creosote as a flotation oil.

(n) Round-Table Feed. Low Tonnage (50 Tons). Pulp Heated to 70° F.—The tests (Period 16A) gave a tailing running 0.21% Cu, and a fair grade of concentrate.

(o) Round-Table Feed. Pulp Heated to 70° F. High Speed of Agitators.—It was thought that by increasing the speed of the agitators the amount of feed treated might be increased without decreasing the recovery. The first nine agitators were used and their speed was increased from 265 r.p.m. to 363 r.p.m. The test (Period 16B) was of short duration, as the machine would have racked itself to pieces if operated very long at this high speed. While the test is too short to be conclusive, the indications are that the increased speed was a detriment rather than an advantage. It is thought that there is a critical speed at which the agitators should be run for the most efficient operation. If we go above this speed the power increases much faster than the capacity, and if we go below it we do not get a proper mixing of oil and acid with the pulp. With the agitators running at this speed, the nine cells required 56 hp. including motor and belt transmission loss.

(p) Round-Table Tailing. Low Tonnage (40 Tons). Pulp Heated to 70° F. Low Pulp Density.—These tests (Periods 17

and 18) show average tailings of 0.22% Cu and 0.26% Cu respectively. The concentrate is rather low grade.

(q) Round Table Feed. High Tonnage (90 Tons). Pulp Heated to 70° F.—The tests under Period 19 gave a high tailing, 0.43% Cu, and a good grade of concentrate. The high tailing is due entirely to overloading the machine. Under Period 23 the tonnage treated was just as high, the grade of concentrate only a little lower, and yet the tailing is good, 0.25% Cu. This apparent discrepancy between these two tests is explained, it is thought, by the fact that the slime produced in the mill was considerably more granular during the tests under Period 23 than during those under Period 19.

(r) Round-Table Feed. Low Tonnage (40 Tons). Pulp Heated to 70° F.—In this test (Period 21), the tailing averaged 0.25% Cu and the concentrate was medium grade. The tailing is practically no better with this low tonnage (40 tons) than under Period 23 with the high tonnage (90 tons).

(s) Round-Table Feed. High Tonnage (90 Tons). Air Used in Last Spitzkasten.—It was thought that the introduction of air in the bottom of the last spitzkasten might increase the capacity of the machine and at the same time maintain the same mineral recovery. At first it seemed as though the introduction of the air (Period 22) had resulted in a considerable increase in the capacity of the machine, but when the tests under Period 23 were made, in which the air was omitted, it was found that it was not the introduction of the air which had increased the tonnage.

(t) Conclusions.—1. The economic capacity of the Minerals Separation No. 1 machine when treating slime as produced from the mill, May, 1915, seems to be from 80 to 90 tons.

2. The best combination of reagents for the treatment of slime seems to be sulphuric acid, kerosene sludge acid, wood creosote, and stove oil. There is some question as to the real value of the stove oil. Its principal function seems to be to make a more compact froth.

3. It would not be economical to retain the round tables, as the recovery by treating the slime directly by flotation is just as high as by retaining the round tables and treating the round-table tailing by flotation. The grade of concentrate would probably be the same in either case, but any difference would be in

favor of treating the round-table feed directly by flotation. The heating of the round-table tailing pulp, on account of its low density, would increase the cost of the flotation.

4. In treating the round-table feed directly by flotation, the resulting tailing should assay 0.30% Cu, or less, with a concentrate carrying not over 40% insoluble. Possibly the concentrate can be made much cleaner with no sacrifice in the recovery.

5. It is thought that the best circuit density for the slime pulp for flotation treatment is about 12% solids.

6. It is thought that about 70° F. will be found to be the most economical temperature at which to keep the pulp.

7. Acid seems to be absolutely essential to the successful treatment by flotation of the slime.

8. The addition of air in the last spitzkasten is of no advantage.

9. Any considerable increase in speed of the agitators above a peripheral speed of about 1,300 ft. per minute seems to be disadvantageous.

Treatment of Mill Tailing after Grinding through 60 Mesh.—These tests were made in the Minerals Separation No. 1 machine. Mill tailing from Sections 7 and 8 of the concentrator were elevated and then dewatered. The dewatered tailing was then crushed through 60 mesh (0.25 mm.), either in a Hardinge mill, 10 by 4 ft., or a tube mill, 8 by 12 ft. The grinding mills were operated in closed circuit with a Dorr classifier, the overflow of the classifier being the final product of the system and going to the flotation plant for treatment.

Accompanying is a screen-sizing test of the average final product produced during the test on the Hardinge mill, and is typical of the flotation feed:

(a) Preliminary Tests.—These tests (Period 24) were started immediately after putting the Hardinge mill in operation. At first no sulphuric acid was added, and the pulp was not heated. Kerosene sludge acid contains from 50 to 60% sulphuric acid, so that when this oil is used we could not have a non-acid pulp. We found, however, that the use of acid in addition to that contained in the sludge was of advantage. Some very low tailings were produced during these preliminary tests, but the concentrate was very low in grade. It seemed to be of decided advantage to add the oil ahead of the grinding mill, the latter making an ideal agitator. However, as soon as we began to heat the

pulp ahead of the mill, we found that the acid in the oil and the small amount of copper sulphate formed began to corrode the iron work of the mill. This would not be a serious matter if we used a pebble, or silex-block lining, with pebbles for grinding, but we early abandoned the idea of using silex, or pebble linings, and there was a good chance that as a grinding medium we would find iron balls superior to pebbles. This, of course, precluded the use of any acid ahead of the grinding mill, especially if the pulp was heated.

SCREEN SIZING TEST ON DORR CLASSIFIER OVERFLOW, OR FEED TO FLOTATION MACHINE

Screen Size		Cumulative Per Cent., Solids
Square Mesh	Aperture, Mm. Square	
+16	1.180	0.3
+24	0.730	1.3
+40	0.430	3.0
+60	0.260	5.8
+80	0.210	12.8
+110	0.130	38.5
+130	0.110	42.3
+160	0.085	54.8
+200	0.076	59.3
+240	0.063	62.8
—240	0.063	37.2

It is barely possible that we might find the action of the kerosene sludge acid in a cold circuit so slight that it could be neglected, even though we used steel lining and steel balls. It would be a decided advantage to add the oil ahead of the grinder.

(b) Low Tonnage (125 Tons). Pulp Heated to 70° F. Oil and Acid added in Minerals Separation Machine. Acid Circuit. —The tailing produced during this period (No. 25) averaged 0.07% Cu. The concentrate was too siliceous, averaging 40.1% insoluble. The only reagents used were sulphuric acid and kerosene sludge acid. It should be noted that the product treated during this period contained only 3.1% on 80 mesh (0.20 mm.).

(c) High Tonnage (187 Tons). Same Conditions as under (b), except that Flotation Machine was Divided into Two Parts, Making a Primary and a Secondary Machine, the Secondary Machine being used to clean the Concentrate from the Primary Machine.—

The flow sheet was as follows: The feed pulp was put into the sixth agitator cell, thus making the last 11 cells act as a primary machine. The concentrate from the first six boxes of the primary machine was returned to the first three boxes of the original machine through the two pre-agitators. The overflow from the remaining five boxes of the primary machine was returned to the original feed. The last cell made the usual tailing. The secondary machine made a final concentrate and a middling which was returned to the circuit. The chief reagents used were kerosene sludge acid and sulphuric acid. Small amounts of creosote were used during part of the test, but it seemed to be of no particular advantage.

The tailing during this period (No. 26) averaged 0.11% Cu, and the concentrate averaged 26.9% insoluble. It is thought that this is about typical of the results we may expect from a commercial installation. It should be noted that 14.4% of the flotation feed remained on an 80-mesh screen (0.2 mm.). Finer grinding would undoubtedly result in a lower tailing assay, but we must, of course, set against the increased copper recovery the cost of the finer grinding.

It would be well to call attention to the fact that all averages shown in these flotation tabulations are arithmetical and not geometrical. It was found that the arithmetical average practically checked the geometrical in the test cases, and as the geometrical averages would have involved a great deal of extra work it was considered not worth while to average the results geometrically. For example, Period 26 was averaged geometrically and gave a tailing assay of 0.109% Cu against the arithmetical average of 0.11% Cu. The concentrate averaged 7.777% Cu geometrically, and 7.82% Cu arithmetically. As the daily variations in tonnage and assays are considerable during this period, we would expect to find the arithmetical and geometrical averages diverging more than during the other periods in which the variations are not so great.

(d) Low Tonnage (124 Tons). Same Conditions as under "c," except Turpentine (M. S. 14) added ahead of Grinding Mill, and no Sludge Acid Kerosene used. Pulp Heated to about 70° F.—In this test (Period 27) it was endeavored to take advantage of the grinding mill as an agitator and for this reason a neutral reagent, turpentine, was used. The tailing is high, 0.12%

Cu, considering the comparatively low tonnage of feed and the fact that only 5.2% of the feed was coarser than 80 mesh. The same flow sheet was used as during Period 26.

(e) Low Tonnage (106 Tons). Oil added ahead of Grinding Mill. Non-Acid Circuit. Pulp Heated to about 75° F. Various mixtures of crude turpentine, creosote, and pine oil used during these tests. The mixtures contained from 60 to 70% crude turpentine; 21 to 32.5% creosote; 2.5 to 15% pine oil.—The tailing produced during this period was fairly good, averaging 0.09% Cu, but the grade of concentrate was not good, averaging 41.5% insoluble.

(f) Conclusions.—1. Although not definitely demonstrated, it is thought that the economical capacity of the Minerals Separation No. 1 machine when treating sand tailing crushed through 60 mesh is about 175 to 200 tons per 24 hr..

2. The best combination of reagents seems to be kerosene sludge acid and sulphuric acid. However, a mixture of creosote, turpentine, and pine oil in a non-acid circuit gave good results also. The non-acid circuit, however, seems to require more delicate adjustment and more careful attendance than the acid circuit.

3. The grinding mill makes an ideal agitator, and it is of decided advantage to add the oil ahead of the grinders.

4. The treatment of the mill sand tailing ground through 60 mesh should result in a tailing assaying not over 0.10% Cu and a concentrate carrying not over 30% insoluble.

5. It is thought that the best density of pulp is from 25 to 30% solids.

6. Heating of the pulp to about 70° F. seems to be of advantage, although there is a possibility that this heating may be dispensed with during the summer months without any injurious results.

7. Acid seems to be beneficial but it is not of as much importance as in the treatment of the slime.

Treatment of Mixture of Round-Table Feed and Mill Tailing after Grinding through 60 Mesh.—These tests were made in the Minerals Separation No. 1 machine. It was thought that it might be of advantage to mix the slime and the reground mill tailing for flotation treatment. The kerosene sludge acid, turpentine, and the sulphuric acid used were added in the flotation

machine. In some instances, various mixtures of coal tar (70 to 80%), creosote (17.5 to 22.5%), and pine oil (2.5 to 7.5%) were used with the sludge acid. These were added ahead of the grinding mill.

The average proportion of sand tailing to slime in the mixture treated was 75.7 to 20.1, or 3.8 to 1. In practice the proportion of production of tailing to slime is about 3 to 1; thus the mixture was somewhat deficient in slime. The concentrate produced, 34.1% insoluble, is of a good grade, but the tailing is high, 0.20% Cu. Theoretically, the tailing should have assayed about 0.15% Cu, assuming a 0.10% Cu tailing from the sand tailing and 0.30% Cu tailing from the slime.

Although this test was not conclusive, it was decided, from observation, that it is better to treat the slime and the sand tailing separately. Of course, the slime made in the grinding of the sand tailing is included in the sand tailing for treatment. This slime produced in grinding the tailing is much lower grade and more siliceous than the original mill slime.

Tests with Callow Pneumatic Machine.—Tests made by Mr. Callow at his laboratory in Salt Lake on samples of our mill tailing ground through 40, 60, and 80 mesh, and of our slime, had given such promising results that it was decided to try out the Callow machine on a commercial scale. Accordingly, there was shipped here during September, 1914, five standard Callow cells, 2 by 8 ft., a Pachuca agitating tank and accessory apparatus, consisting of blower and sand pumps. This equipment was installed in the old 80-ton experimental leaching plant and was ready for operation the latter part of October.

In addition to the Pachuca agitator recommended by Mr. Callow, there was built a set of two mechanical agitators. These agitators consisted of a tank about 10 ft. long by 2½ ft. wide and 2½ ft. deep, in which revolved a horizontal shaft carrying a set of paddles. These agitators were belt driven from one motor and required a total of 25 to 30 hp., including motor, belt, and countershaft power loss. The agitators seemed to work well and had a combined capacity of about 60 tons of slime per 24 hr.

Power readings made on the blower which furnished the air for the five Callow cells gave the following results:

Air Pressure, Pounds	Input to Motor, Hp.	Shafting, Hp.	Net to Blower,* Hp.
4	25.8	8.8	17.0
5	35.4	8.8	26.6
6	47.4	8.8	38.6

* Includes motor loss.

Treatment of Round-Table Feed and Tailing.—(a) Round-Table Feed. No Acid.—During the first four days air agitation was employed, using the Pachuca tank. With a feed of 60 to 80 tons, the results were very poor. The air agitator did not have sufficient capacity. During the last five days of this period (No. 32) mechanical agitation was used and gave much better results.

(b) Round-Table Feed. Air Agitation.—This test (Period 33) which was of 16 days' duration gave an average tailing of 0.35% Cu, and a concentrate carrying 31.6% insoluble. The capacity per cell seems to be about 15 to 20 tons of slime per day. Sludge acid and sulphuric acid, with no creosote or stove oil, seemed to give as good or better results as when creosote was used.

(d) Round-Table Tailing. Mechanical Agitation.—This test (Period 34) of 27 days' duration, gave an average tailing of 0.30% Cu, and a concentrate assaying 34.2% insoluble. The average tonnage per cell was 20 tons per day. The principal oil used was kerosene sludge acid, together with sulphuric acid.

(d) Round-Table Tailing. Mechanical Agitation.—This test (Period 35), of four days' duration, gave an average tailing of 0.32% Cu, and a final concentrate of about 60% insoluble. (The rougher concentrate for the first two days should be included in the average final concentrate.)

(e) Conclusions.—1. On our slime, air agitation is not as satisfactory as mechanical.

2. The capacity of one standard Callow cell is about 15 to 20 tons of slime per day.

3. The Callow machine produces a clean concentrate but does not give as clean a tailing as the Minerals Separation machine.

4. The Callow machine is more sensitive and requires closer attention than the Minerals Separation machine.

5. The cost of repairs would probably be less on the Callow machine than on the Minerals Separation machine. This cost, however, is comparatively small for either machine.

6. The power required per ton treated in the Callow system is just about the same as that required in the Minerals Separation machine.

In all of these tests the original feed was divided among the Callow rougher cells, operating in parallel. As a rule, there was one cleaner cell operating also. When this was operating the concentrate from the rougher cell went to it, the cleaner making a final concentrate and a middling which was returned to the system. The rougher cells made the final tailing.

Treatment of Mill Tailing after Grinding through 60 Mesh.—(a) Preliminary Test.—During the first few shifts the mechanical agitators at the Callow plant were used, but it was soon found that they were not required—that the grinding mill gave sufficient and thorough agitation.

Kerosene sludge acid was the only oil used during this period, and was added ahead of the grinding mill. Sulphuric acid was added ahead of the flotation cells. The tailing for this period averaged 0.10% Cu, and the concentrate carried an average of 42.2% insoluble. The pulp was heated just ahead of the flotation cells (Period 36).

(b) Kerosene Sludge Acid Added Ahead of Grinding Mill.—The flow sheet was modified slightly during Period 37. Instead of sending the entire rough concentrate from the rougher cells to the cleaner cells, only the first half was sent to the cleaner, that coming off the half nearer the tailing end of the machine being returned as middling to the original feed. This resulted in giving the cleaner cell a richer feed and, in turn, enabled the cleaner to make a higher grade concentrate. This period shows some very good results, a tailing assaying 0.11% Cu and a concentrate carrying 27.9% insoluble. Here, again, is brought out the splendid agitation and mixing obtained in the grinding mill.

(c) Neutral Circuit. No Acid. Turpentine Added Ahead of Grinding Mill.—In this test (Period 38) no acid was used. Turpentine was added ahead of the grinder. The tailing averaged 0.16% Cu, and the concentrate carried 35.1% insoluble. It should be noted that in this test tonnage treated per cell was only 58.2 tons as against 75.6 tons in the preceding test.

(d) Neutral Circuit. Same Conditions as under "c" except Lower Tonnage per Rougher Cell.—During this period (No. 39) the average tonnage treated per rougher cell was only 39.9 tons. The tailing was high, 0.18% Cu, and the concentrate low grade, 47.5% insoluble.

It is evident from the work in this and the preceding period that turpentine will not give us good results in a neutral circuit.

(e) Mixtures of Coal Tar, Creosote and Pine Oil Added Ahead of Grinder. Neutral Circuit.—The tests during Periods 36 and 37 show a tailing of 0.13% Cu, and a low-grade concentrate,—45.3% insoluble. The results are not nearly so good as those obtained in the acid circuit.

(f) Same Conditions as under Period 40, except the Rougher Cells Operated in Series instead of in Parallel.—During this test the original feed went to No. 2 rougher and the tailing from No. 2 rougher was fed to No. 1 rougher, the latter making a final tailing. The concentrate from the No. 2 rougher went to the cleaner and that from No. 1 was returned to the feed as middling. The final tailing averaged 0.11% Cu, but the concentrate was rather low grade, running 38.7% insoluble.

(g) Conclusions.—1. The capacity of the standard Callow cell when treating ground mill tailing is about 75 tons per day.

2. No other agitation is required if the reagents can be added ahead of the grinding mill.

3. The use of acid seems to be of considerable advantage.

4. On account of utilizing the grinding mill as an agitator the Callow machine requires less power than the Minerals Separation machine.

5. The Callow machine is more sensitive and requires more attention than the Minerals Separation machine.

Soluble Copper in Flotation Tailing.—Samples of tailing pulp were sent to the laboratory and the soluble copper was determined. The tailing from the round-table feed contained 0.141 gram of soluble copper per liter of solution. The tailing from the round-table tailing contained 0.084 gram of soluble copper per liter of solution.

Disintegration of Flotation Froth.—In order to break up the froth in the flotation concentrate a saucer-shaped disk 3 ft. in diameter was constructed. This was revolved at a speed of 300 r.p.m. inside a circular tank. The concentrate pulp was fed on to

the disk at the center and was thrown out against the sides of the tank. The impact broke up the froth to a great extent. No test was made on the disintegrator.

It was noted early in the experimental work that an elevator made a good froth breaker, the impact of the pulp discharge at the head of the elevator serving to break up the bubbles, to a large extent. A test made at the experimental Callow flotation plant showed that the rough concentrate pulp was reduced 75% in bulk in passing through an elevator. As to apparatus, it was concluded that the Minerals Separation was best adapted to the work at Anaconda.

Summary of Flotation Tests—Minerals Separation Machine No. 1.
Treatment of Slime, Round-Table Feed and Tailing

Period	Feed				Concentrate Assay				Tailing Assay, Per Cent. Cu	Per Cent. Cu Recovered	Temperature, °F.			Reagents Used, Pounds per Ton						P. T. & T. Co. 400
	Tons per 24 Hr.	Assay, Per Cent. Cu	Density, Per Cent. Solids	Hours in Operation	Per Cent. Cu	Per Cent. Insol.	Per Cent. FeO	Ag Oz. per Ton			Feed Pulp	Pulp in Machine	Difference	Sludge Acid	Wood Creosote	Stove Oil	H_2SO_4	Turpentine	Tar Creosote	
1	Preliminary																			
2	61.0	2.04	13.7	120.0	8.2	54.7	13.7	.....	0.31	89.3	54	89	35	3.8	2.4	0.36	12.6			
3	64.2	2.07	14.9	72.0	7.2	62.0	10.8	6.0	0.38	86.0	51	51	0	3.6	2.3	0.29	13.3			
4	56.2	2.08	13.6	48.0	8.3	51.1	15.6	6.7	0.27	90.4	53	125	72	3.9	2.8	0.33	12.6			
5	52.2	1.16	11.7	56.0	6.6	66.1	7.8	5.8	0.33	75.5	54	54	0	3.5	3.8	0.37	15.2			
6	48.2	1.08	11.1	72.0	7.2	62.1	8.9	6.8	0.31	74.3	53	106	52	3.9	4.2	0.29	11.8			
7	63.8	2.24	22.5	40.0	9.2	52.9	12.8	7.8	0.28	90.3	53	96	43	2.7	2.4	0.33	12.5			
8	104.8	2.19	24.5	88.0	8.9	57.5	11.2	6.45	0.63	76.6	53	96	43	3.1	2.4	0.32	13.9*a*			
9	94.7	2.25	22.7	120.0	8.7	60.5	9.2	6.45	1.34	47.5	54	54	0	2.0	2.2	0.21	16.4			
10	60.4	2.20	14.5	96.0	10.1	52.6	12.4	7.9	0.50	82.0	48	48	0	3.3	2.9	0.21	16.5			
11	58.2	2.39	14.5	144.0	9.2	53.3	12.8	6.8	0.33	89.5	50	81	31	3.5	3.4	0.42	12.7			
12	56.1	1.11	18.1	24.0	5.9	71.8	5.2	4.4	0.53	57.8	52	72	20	3.7	3.7	0.28	16.1			
13A	60.6	1.11	13.5	184.0	5.8	71.3	5.6	4.2	0.28	79.1	52	80	28	3.7	3.5	0.30	16.8			
13B	51.6	1.35	11.1	32.0	2.0	85.0	2.5	1.0	1.04	47.8	51	80	29	5.5	3.1	0.27	00.0			
14A	31.7	1.17	5.6	48.0	6.8	66.2	7.4	4.6	0.30	77.8	50	80	30	5.1	4.3	0.32	18.9	3.7		
14B	42.6	1.17	6.8	24.0	5.9	68.0	7.2	4.6	0.24	82.7	50	71	21	4.4	.....	0.37	21.0			
14C	40.4	1.12	6.7	80.0	6.1	67.2	8.3	4.8	0.23	82.5	52	80	28	4.4	4.0	0.28	18.5			
14D	40.0	1.13	6.5	16.0	9.8	54.3	11.5	6.6	0.32	....	52	81	29	5.0	4.2	0.73	20.1			
15A	42.7	2.35	9.4	40.0	9.3	47.2	17.0	6.7	0.23	92.5	48	82	34	4.3	4.5	0.33	20.7			
15B	48.0	2.51	8.0	32.0	13.4	33.6	20.9	8.8	0.26	91.5	48	78	30	5.4	.....	0.34	20.0	...	4.7	
15C	49.0	2.52	8.8	80.0	10.8	44.2	18.4	8.3	0.25	92.2	45	71	26	3.8	.....	0.41	19.3	3.3		
15D	49.4	2.25	9.7	40.0	11.0	40.7	19.3	8.1	0.38	86.0	46	70	24	9.0	.....	0.33	19.3			
15E	50.2	2.52	9.3	40.0	14.3	28.9	23.6	11.4	0.48	83.8	44	70	26	4.0	.....	0.49	18.6	...	4.5	
16A	49.0	2.55	11.5	248.0	9.7	48.8	16.0	7.7	0.27	92.1	44	68	24	3.2	4.7	0.46	20.9			
16B	55.2	2.58	13.7	24.0	10.6	48.5	15.6	9.2	0.56	83.0	45	66	21	5.9	4.6	0.31	23.2			
17	40.0	1.10	5.8	576.0	7.5	63.0	9.3	5.9	0.22	82.4	43	69	26	4.7	4.8	0.30	16.7			
18	42.0	1.11	5.8	334.9	7.0	65.9	7.7	4.7	0.26	79.5	40	70	30	4.1	4.54	0.19	19.6			1.61
19	90.0	2.57	15.7	236.4	14.8	31.3	22.1	11.2	0.43	85.8	39	72	33	2.54	1.38	0.14	13.1	...	...	1.73*b*
20	60.2	2.74	15.3	211.3	12.0	38.3	20.6	8.8	0.33	90.5	39	70	31	3.27	.....	0.26	15.6	...	...	3.60
21	40.9	2.48	15.1	313.1	10.1	43.7	18.8	6.9	0.25	92.3	40	76	36	6.15	.....	0.29	19.5	...	...	1.88
22	88.2	2.54	15.9	417.7	11.9	39.4	20.1	8.4	0.25	92.3	41	74	33	2.99	.....	0.13	13.5	...	...	1.52
23	89.9	2.60	15.4	283.7	12.3	36.4	20.8	9.3	0.27	91.6	43	74	31	3.27	.....	0.18	14.9	...	...	
30*c*	93.3	2.55	10.7	336.0	8.3	55.2	13.3	5.8	0.41	99.3	44	65	21	3.7	3.4	0.71	21.1			
31*c*	45.1	1.10	5.7	720.0	4.5	74.3	5.7	.....	0.27	80.3	44	65	21	3.9	3.3	0.34	18.7			

Note.—This table gives the average of the results of each period.

a During this period about 1.8 lb. of fuel oil per ton of feed was used with the other oils.

b During two days of this test Midwest Refining Co. sludge acid was used along with the other reagents at the rate of 3.69 lb. per ton, and on another day Western Oil Co. sludge acid at the rate of 1.04 lb. per ton. No improvement found in either instance.

c These tests were made in M. S. Machine No. 2.

SUMMARY OF TESTS IN MINERALS SEPARATION MACHINE NO. 1.—CONTINUED

TREATMENT OF SAND TAILING FROM MILL, GROUND THROUGH 0.25 MM.

Period	Feed				Concentrate Assay				Tailing Assay, Per Cent. Cu	Per Cent. Cu Recovered	Temperature, °F.			Reagents Used, Pounds per Ton						P. T. & T. Co. 400
	Tons per 24 Hr.	Assay, Per Cent. Cu	Density, Per Cent. Solids	Hours in Operation	Per Cent. Cu	Per Cent. Insol.	Per Cent. FeO	Ag Oz. per Ton			Feed Pulp	Pulp in Machine	Difference	Sludge Acid	Wood Creosote	Stove Oil	H_2SO_4	Turpentine M.S. 14	Tar Creosote	
24	Preliminary																			
25	125.0	0.62	22.3	55.8	6.35	40.1	26.8	4.2	0.07	93.0	40	69	29	2.5	.....	.....	7.6			
26	186.7	0.87	30.9	472.6	7.82	26.9	32.5	5.4	0.11	88.6	43	69	26	3.1	0.7	.....	4.9	.....	.....	0.3[1]
27	124.1	0.67	26.1	120.5	5.42	42.2	25.4	4.2	0.12	84.0	42	72	30	.....		0.3	1.3	3.9		

[1] Average of four days' test. Results not improved by this oil. For two days 1/7 lb. of Standard Oil Co. kerosene sludge acid per ton of feed was used along with the P. T. & T. Co. No. 400. No marked improvement noted. Wood creosote used for only six days. Tailing assayed about 0.09 during this time.

TREATMENT OF ROUND-TABLE FEED BY FLOTATION PROCESS. MINERALS SEPARATION MACHINE NO. 2A

Date, 1915	Rate per 24 Hr.		Assay Feed, Per Cent. Cu	Temperature of Circuit, °F.	Tailing Assay, Per Cent. Cu	Concentrate, Per Cent.			Reagents, Pounds per Ton			
	Gallons Pulp	Tons Solids				Cu	Insoluble	FeO	H_2SO_4	M. S. 37	P. T. & T. Co. 400	M. S. 8
2-27	58,900	39.5	2.59	90.9	0.86	8.3	54.4	14.3	26.3	6.9	2.3	0.15
2-28	40,200	29.8	2.50	87.2	0.73	9.8	36.9	27.1	30.1	7.0	3.2	0.04
3-1	44,600	29.7	2.50	86.1	0.93	10.0	46.4	18.3	26.1	7.3	5.3	0.50
3-2	49,300	34.6	2.55	92.6	0.50	5.9	62.2	11.9	20.9	6.5	2.7	0.20
3-3	52,200	36.4	2.62	90.7	0.47	6.0	60.5	12.6	22.3	6.1	1.3	0.07
3-4	55,100	39.7	2.54	86.0	0.61	7.0	58.0	13.0	17.6	5.1	2.4	0.03
Average	50,050	34.9	2.55	88.9	0.68	7.8	53.1	16.2	20.5	6.5	2.9	0.16

The machine was in good running order, mechanically, on Feb. 27, 1915. There seemed to be too much agitation at first, so No. 4 impeller was dropped off shaft. Machine ran this way until Mar. 3, when the No. 2 impeller was dropped. Air was blown in under each impeller. With first and third impellers operating, the input to the motor was 32 hp.

Summary of Flotation Tests—Callow Pneumatic Machine

Treatment of Slime

Period	Hours in Operation	Number of Rougher Cells Operating	Air Pressure Pounds per Square Inch	Feed: Per Cent. on 80 Mesh	Feed: Density, Per Cent. Solids	Feed: Assay, Per Cent. Cu	Feed: Tons per Rougher Cell	Temperature of Pulp in Circulation	Reagents Used, Lb. per Ton: H_2SO_4	Sludge Acid	Crude Wood Creosote	Stove Oil	Turpentine	Fuel Oil	Pine Tar	Final Tailing, Per Cent. Cu	Final Concentrate: Per Cent. Cu	Final Concentrate: Per Cent. Insol.	Final Concentrate: Per Cent. FeO	Middling, Per Cent. Cu	Rougher Concentrate: Per Cent. Cu	Rougher Concentrate: Per Cent. Insol.	Rougher Concentrate: Per Cent. FeO	Per Cent. Cu Recovered
32	Preliminary																							
33*a*	246.5	2.8	4.52	....	14.7	2.57	15.0	72.4	18.4	5.75	3.04*b*	0.51*b*	...	....	...	0.35	13.7	31.6	23.6	1.71	6.7	54.4	13.8	88.6
34*c*	500.1	2.0	4.00	....	15.2	2.57	20.2	71.1	12.4	3.82	3.13	0.35	...	0.24	...	0.30	12.0	34.2	23.4	1.69	6.0	56.8	13.3	90.6
35	42.8	3.3	4.00	....	5.6	1.66	11.4	68.8	18.5	9.05	.....	.....	...	0.71	...	0.32	12.7	53.9	10.0	....	6.0	64.8	6.5	83.3
	Treatment of Mill Tailing																							
36	249.0	2.0	4.00	13.4	27.5	0.64	108.5	64.5	3.3	2.4	....	....	....	....	...	0.10	6.53	42.2	25.0	0.52	2.9	79.1	7.4	
37	120.8	2.0	4.00	6.5	27.1	0.77	75.6	72.6	5.3	2.5	....	....	....	....	...	0.11	7.81	27.9	32.4*d*	1.25	3.8			
38	40.0	1.6	3.90	6.9	22.1	0.65	58.2	69.9	0.0	0.0	....	....	2.7	...	...	0.16	6.23	35.1	28.8*e*	1.18	3.2			
39	76.7	.....	2.60	....	22.0	0.72	39.9	67.4	....	.....	....	.....	3.09	.....	...	0.18	5.6	47.5	32.2					

a Air agitation used throughout this period.
b These oils were used only during first five days.
c Mechanical agitation used throughout Period 34.
e Concentrate assayed 5.2 oz. silver per ton.
d Concentrate assayed 4.8 oz. silver per ton.

CHAPTER VIII

THE APPLICATIONS OF FLOTATION

Among metallurgical processes flotation is apparently unique in that it is applied to a wide variety of ores. Many operators have expressed surprise at the extent of the field for flotation, but when one considers that it is merely a variation of concentration and that all possible kinds of ores are concentrated, it is not unusual, after all, that it should be applied to so many ores. Flotation really is not a complete metallurgical system, but only an incident or a step in the long process of extracting metal from its ore. Flotation does not extract metal from any ore, but simply separates the greater part of minerals from a large proportion of gangue, just as any other concentration process is designed to do. Flotation does it, on many ores, so much better and so much cheaper than gravity concentration that it is being widely adopted, and the method deserves all the attention it can get.

The process is so new that clearly defined systems of application have not yet been pointed out. At present it is merely an empirical matter involving an extraordinary amount of testing to see, first, whether flotation is adaptable to an ore, and second, if it is, how best to adapt it. No one process or system will apply to all possible ores, even of one metal, and flotation has up to this time been applied to copper, zinc, lead, molybdenum, gold, and silver, with possible applications in some other lines.

Some Fixed Principles.—There are, however, a few principles that can be considered as practically fixed. One of the most definite of these is that oxide ores, as such, are not floatable. As a rule it is impossible to get an oxide, *per se,* to float, although it is possible to change the surface film of an oxide particle into such a form that the particle will float. The reasons for this have been discussed in the chapter on theory, and from that it has been determined that the contact angle of an oxide particle is not such as to permit the necessary application of surface ten-

sion forces. Oxide particles seem to act with oils very much as gangue particles do, refusing to form a film upon them of such character that the particle will be enabled to present a contact angle such as to enable it to float. Carbonate particles are also difficult to float, but sometimes it can be done. In general, however, it may be said that the carbonate particles follow the inclinations of the oxides and do not float unless a surface film of proper kind has been formed upon them.

The Character of Colloids.—Another definite fact that is fairly clearly recognized is that colloids are not favorable to flotation. This has also been discussed in the chapter on theory, the basic reasoning being that colloids are particles so finely divided that they approach the solution state, and it will be admitted that particles or molecules in solution are not conducive to commercial flotation. The dispersion is such that what are ordinarily called flotation tendencies have little effect upon them. It is not impossible, however, to practice a selective flocculation and sedimentation, a point that has already been touched upon in the chapter on testing ores. A thorough study of colloids is of great value to the student of flotation as well as to one who cares to understand thoroughly the basic principles of any wet milling process. The literature of colloids is not rich, in English, and perhaps the clearest available explanation of the subject is contained in the series of articles by E. E. Free.* A thorough study of this enlightening exposition will be of great benefit to any one interested in ore dressing, but it is too lengthy to be touched upon here. So far these are about the only points that have been definitely settled, although some others seem to be fairly apparent. It is true that sulphides are floatable, possibly the most easily floatable of all the minerals, and in general it may be said that all sulphides are susceptible to the flotation process, but even this must be somewhat modified, since with some of the sulphides better results are secured by some other process, and some complex sulphides do not even give satisfactory results through the application of any of the variations of flotation now known and practiced.

Flotation to Produce Two or More Products.—In addition to the applications of flotation to ores from which one product is to be made, there are other ores in which several products may or

* "Colloids in Ore Dressing," *Eng. and Min. Journal*, Feb. 5, *et seq.*, 1916.

must be made. Such ores constitute a distinct problem and they must be worked out, each on its own merits. Thus, when an ore containing zinc and lead is to be treated, and this intermingling of the zinc and lead constituents is intimate, as it usually is in such ores, a different scheme of treatment must be inaugurated. Some of the most important uses of flotation are in just such cases, an example of which is found in the Coeur d'Alene district of Idaho. Here zinc, lead, and silver occur in the same ores, sometimes together with copper. All of these metals are to be recovered and as nearly separate as it is possible to do so. This is being done successfully, the ways and means for which will be detailed.

To begin with the simplest problem would be the most logical process, therefore it would be well to consider the recovery of a single sulphide, take copper for example, from ordinary ores. The first thing that should be recognized is that it is almost impossible to secure anywhere near complete extraction and high-grade concentrates at the same time and through the same operation. The procedure, then, is to make a first concentration in which the greatest possible percentage will be recovered from the ore without regard to the grade of the concentrate secured. The second operation, then, is to work on the low-grade concentrate secured, and by a repetition of processes to segregate the valuable portions into still smaller bulk, leaving a low-grade middling for further treatment. This middling is usually either reground or returned to the secondary system for retreatment. The two processes are in general known as "roughing," that is the first process of extracting as much of the mineral as possible from the ore bulk, and "cleaning," that is the producing of high-grade concentrate from the low-grade material first extracted from the ore bulk.

Flotation a Principal or Secondary Process.—Before going into the actual flotation work, however, one has to consider, in a scheme of treatment, whether or not flotation is to be the principal treatment or whether it will be a secondary consideration. To say that flotation may be the sole process of metallurgy in a given case, is to make a statement entirely too broad for general use. Some ores, it is true, may be treated by flotation only, but it is reasonably certain that such ores are limited in number and that the statement can by no means be made a widely applicable

rule. Ores that are coarsely crystalline in nature can best be treated by stage crushing and stage concentration, beginning with jigging. By this means a large amount of expensive grinding and regrinding is avoided, and concentrates are recovered as quickly as possible. Of course, in such case, the finely divided part of the ore, or slimes, would probably be best treated by flotation, but with an ore of this character there is no reason for doing any more grinding than is just enough to liberate the minerals and allow them to be separated from the gangue. It may be said that this particular point is just the one that limits a reasonable application of flotation and other concentrating systems. The mineral particles must be liberated from the gangue by crushing and then separated by concentration. Therefore crushing should be carried only far enough to liberate these particles, and the concentration process then applied to separate one from the other should be appropriate to the size of the grain thus freed. If the grains are all coarse, then under ordinary circumstances jigging, table concentration, or any form of ordinary gravity concentration is the one that should be applied. If the grains are fine, then flotation may do the better work and at a lower cost. Of course it may be possible that in special instances, such as with very heavy gangues approximating the weight of the mineral itself, fine grinding and flotation will have to be resorted to in order to get satisfactory results, no matter what the size of the mineral grains.

One authority, referring to the discussion as to whether or not flotation should be used as an auxiliary, said that were flotation always considered as secondary instead of a primary process, a large portion of the benefit of its economy of operation would be lost, and while it is true that some ores would justify coarse crushing, jigging and table work previous to flotation, a large number of ores, especially the lower-grade porphyry copper ores and the closely included lead ores, will show a distinct benefit by making flotation the primary treatment. Where initial crushing is fine enough for flotation, and where such crushing can be obtained entirely by a crusher followed by a ball mill, an extremely simple and effective flow sheet can be formed. In most cases where this is done, the tailings from flotation are run over tables of the Wilfley or Deister type. As previous to

this tabling practically all the fine material that can be saved has already been removed by flotation, the table feed requires no preparation by sizing or classification and a large tonnage can be run over each machine. Even on ores where the mineral occurs coarse, we are beginning to believe that the best method of treatment will be to crush to six, eight, or ten mesh, rough on tables of the ordinary roughing type, recrush these rougher tailings and send them direct to flotation. Flotation treatment has proved itself to be not only extremely efficient but permits a simple flow sheet, cutting out a large number of elevators, trommels, and other kindred annoyances.

Floating a Selected Portion of the Ore.—While there is much of logic in what this authority points out, it is somewhat difficult to accustom oneself to the idea of concentrating on tables a flotation tailing. It would ordinarily seem more reasonable, as I have already pointed out in a previous paragraph, to crush the ore only to that fineness required to liberate the mineral grains. Now, if a large quantity of mineral grains can be liberated at, say 10 mesh, and a certain percentage of that mineral can be recovered by jigging or tabling, then it would seem unreasonable to crush that same material to 60 or 80 mesh in order to treat it by flotation. It is not as if the same bulk had to be treated by flotation anyway, since it is not always impossible to separate by jigging, tabling, and other well-known milling methods, first a high-grade concentrate to be regarded as a finished product, a middling product containing practically all the remaining value of the ore, and a tailing that can be discarded. If we subtract from the original ore bulk, then, the finished product that is saved and the tailing that is discarded, we have left only the middling to be reground and treated by flotation, thereby reducing materially the tonnage to be handled by that process. All in all, it seems a very cheap and reasonable way of going at it. However, since flotation has seemed to reverse practically all of our theories, many of which we formerly held dear, I am not going to make the mistake of advocating too strenuously any one procedure, since I am of the opinion that flotation is by no means in its finished form at the present time, and there may be many improvements and developments that will change all the ideas that we have formed.

Another authority, speaking of this same subject, points out

that it is usually not advisable to draw a line of demarcation between sand and slime, reserving only the latter for flotation. In this case, the reference to slime does not mean colloids but only the very fine portion of the ore which may be granular or not as the case may be. As we have already seen, flotation does not apply to colloids, but may apply to very fine material when it is flocculated. A system that has often resulted in improved mechanical efficiency, is to separate sand for table concentration, making a clean, high-grade concentrate without trying to clean absolutely the tailing, and then to regrind the tailing and add it to the slime, the whole being then subjected to flotation. This authority, however, points out that this is especially true for gold and silver work. In general, when the concentration ratio is high, that is when there is only a small portion of mineral in comparison to a very large proportion of gangue, authorities seem to believe that flotation would be the best sole process to be applied. In such cases gravity concentration is considered an auxiliary. When the ratio of concentration is low, it is considered better practice to begin with gravity concentration and finish up with flotation. This is practically as I have outlined it in a previous paragraph, and some ores are such that they will be well handled by this process. In cases where new and modern concentration mills have been constructed based on gravity practice, it would be unwise to waste all the money involved in that work, and the point of wisdom is to use flotation as an auxiliary to the gravity-concentration scheme.

As an example of ores in which the ratio of concentration is very high, we can point to the porphyry coppers, such as Inspiration, Miami, Utah Copper, Ray Consolidated, and the others of like type. Here the percentage of copper is very small and is highly disseminated through a large proportion of gangue. Here, so the copper authorities point out, it is best to apply flotation at once, since the mineral particles are so small that the ore has to be ground very fine to liberate them anyhow, and that their handling by flotation alone requires a much cheaper and simpler installation. If it should develop, however, and the scheme is by no means impossible, that the finely ground porphyry copper ores can be treated primarily by selective settling in some such machine as a Dorr thickener,

it would be better to eliminate as tailing the largest possible percentage of such material, reserving only the part containing mineral for flotation concentration. The question of selecting settling has already been treated by O. C. Ralston,* who points out his practical experiments along that line and demonstrates the possibility of commercial applications of the system. They have not been successfully accomplished yet, but are by no means impossible.

It seems that flotation processes are limited on one hand by the size of the particle and it is useless to treat a pulp by the flotation process unless all of it has been ground to such a point that the particle will float under the best obtainable conditions. There would be little use, for example, in attempting to float a ¼-in.-mesh product, and while it is likely that no one would be foolish enough to make the attempt, the line of limitation between a floatable particle and a non-floatable one is not clearly enough defined in the mind of the ordinary operator. The size of the particle is one of the important influencing conditions, and all operators should recognize that. If it is possible to make a good product by gravity concentration on coarse material, it should certainly be done, since the expense of fine grinding is then avoided. But where the mineral is extremely finely divided and disseminated in the ore, there is no particular advantage in performing stage concentration because no high-grade product can be obtained on coarse grains.

The procedure already referred to as being applied in the Coeur d'Alene, where zinc, lead, and silver are to be obtained by concentration, may now be investigated. Most of the mills in that district have been using gravity concentration for a number of years. The process is started with jigging, and then proceeds to coarse-table and fine-table work, finally ending up with flotation on the finer products. It is to be remembered, however, that but few of these mills are new, and many of them contain a heterogeneous collection of concentration machinery that represents a gradual development from the first steps of the process up to the most modern improvements. One of the new mills in this district is that of the National Copper Mining Co., and in this plant, which will be treated in detail in another chapter, the ore is subjected to crushing, screening, classifica-

* "Control of Ore Slimes," *Eng. and Min. Journal*, Apr. 29, 1916.

tion, and table concentration, and also regrinding, before going to the flotation machine. A system of primary roughing and final cleaning is carried out.

The Coeur d'Alene District.—At the older mills of the district it has been difficult to secure permission to publish data, and for that reason no definite statements can be made at the present time. One interesting fact, however, that has been made public before is the installation of a Macquisten plant at the Morning mill of the Federal Mining and Smelting Co.

In general the ores of the Coeur d'Alene are such as I described * in an article on this subject. Gold and silver have been found in native form but do not usually exist that way. Among the minerals occurring in that country, galena should be metioned first since it is the most important, being the source of a large production of lead and the medium that carries a great part of the silver. It is probable that galena is the most widely distributed mineral in the district with the possible exception of pyrite. The sulphide of antimony (stibnite) is not rare, and is common in the Wardner district. Chalcocite is found occasionally, but is rare. Sphalerite, a well-known zinc mineral, is rather widely distributed, but in quantity not so great as might be expected in view of the galena quantity. Siderite, the carbonate of iron, is the most abundant gangue mineral of the Coeur d'Alene silver-lead deposits and is one of the most important features that has to do with the metallurgy of the district. The minerals occurring there form a hard combination to handle, and flotation has been a great assistance to the profit-making endeavors of the metallurgists concerned.

At the Gold Hunter mill a complete system of stage crushing and concentrating is in force, the concentration beginning with jigs and progressing through tables down to finally the roughing and cleaning flotation machines. At this mill the Callow pneumatic system is in use, as it is in a great many other plants in the district.

At other mills of the district, the feed is all crushed to pass 100 mesh, although this is not usual. At one mill, material passing 60 mesh is treated by flotation, the tailings being then reconcentrated on gravity tables. Some authorities claim this to

* "Metallurgy in the Coeur d'Alene," *Eng. and Min. Journal,* Nov. 20, 1915.

be rather poor practice, since none of the galena products between 60 and 100 mesh will float, and must be caught on the tables. In this case, it would probably be better practice to treat the + 100-mesh material on tables first, making a clean tailing and low-grade middling, the latter of which could be reground and then treated successfully by flotation. The question of oils in the Coeur d'Alene is not yet settled, but the practice is in line with that of other progressive districts in which a larger quantity of an oil to be used for oiling the mineral particles is combined with a much smaller quantity of a frothing oil.

In the Globe-Miami district, of Arizona, several plants are using flotation, and at least one of them has been built with an idea to incorporating flotation in the principal flow sheet. At the Inspiration mill, for instance, ore is crushed in ball mills, into which the flotation oil and mill water is also added. The material is then classified and the slime thickened in Dorr machines, the underflow from which runs to flotation. The sand portion is also sent to flotation, but through a different set of cells which are operated in a slightly different way. At this mill there are several different kinds of machines, including the Callow, the Minerals Separation and a special type of machine developed at the works. At the Old Dominion mill, the ore is somewhat different from that treated at the Miami and Inspiration. In this case jig concentrates are made and Minerals Separation machines are used for treating the slimes. Flotation here produces a sort of an end product, and is only a small portion of the entire mill concentrate. At the Miami mill, Callow cells are used for final treatment of slimes, since this mill was not designed primarily to use flotation.

Floating Precious-Metal Ores.—While flotation has not been extensively applied to silver-gold ores, there is no reason why gold-bearing sulphides or gold-bearing silver sulphides, or silver sulphides alone, should not be treated, at least in part by flotation. A noted authority on cyaniding has announced his belief that the treatment of ordinary silver-gold ores will be, in the future, a combination of cyaniding and flotation. By this system a stage-grinding series is carried out, no doubt as has been done heretofore, beginning in crushers and continuing with either stamps, rolls, chilean mills or some such inter-

mediate grinding machines, and finishing up with tube-mill grinding. The products from the tube mills will then probably be classified, a selected fine portion going to flotation, the sand portion being concentrated on tables and then leached by cyanide. This would probably make a very cheap process to operate and a rather inexpensive one to install. The alternative, as has already been pointed out, is to regrind the sand after table concentration and send it, too, to flotation. In many cases this might be a more satisfactory process, particularly if the table product is divided into high-grade concentrate, low-grade middling, and barren tailing. In this case the latter could be discarded altogether and only the middling reground and treated by flotation, making a very simple flow sheet to maintain.

The procedure to be followed in installing flotation is, of course, one that has not been definitely settled for all cases and one that requires considerable study to work out in the proper way. The natural development of the process is in pointing out such facts, from time to time, as will add to the possibility of forecasting results that will follow certain systems. At present, however, a great deal of study and a long, careful, persistent system of experimentation is necessary in every application.

CHAPTER IX

EXAMPLES OF FLOTATION PRACTICE

Since the first days of flotation the process has appeared particularly attractive to Australian operators who have given a great deal of attention to its development. It would not be too much to say that in the early days the Australians were the only ones who seemed to place much serious importance upon this process and many important facts were discovered there. Naturally, in the incubating days, the flotation process proved to be a continual source of trouble and exasperation to its operators, and the Australian metallurgists deserve a great deal of credit for the successes they have extracted from a system that did not appeal strongly to operators in other parts of the world. Their perspicacity has been fully justified by recent developments of the art and the spread of flotation to all corners of the universe.

In the early days those who are familiar with Australian metallurgical development agree that flotation with and without oil occasioned more hard labor and real desperation than anything that has appeared in recent years. For this reason it is of interest to note some of the successful plants that have brought Australia to the front in flotation practice.

The Central Mill, Broken Hill.—A paper by James Hebbard * describes the operation of the process at one of the large mills in Australia. He points out that while concentrating the galena in the lead ore produced from the Central Mine, a valuable by-product was obtained in the form of slime assaying 18% lead, 20% zinc, and 16 oz. of silver per ton. This came from an ore in which the quartz and rhodonite were the chief gangue minerals. In the course of ordinary operations it had long been observed that a froth was formed containing high metallic values, in silver and lead particularly, whenever con-

* "Flotation at the Central Mine, Broken Hill," *Proceedings of the Australasian Institute of Mining Engineers*, Nov. 10, 1913.

ditions were favorable, as for instance, where the rotation of trommels, or the splash of the elevators or the motion of jig plungers produced a violent agitation of the mill water containing slime. Early in 1901 a series of experiments was carried out for the purpose of reproducing and accentuating the conditions responsible for this valuable float concentrate. Experiments and tests, extending over several months, were made on slime of various degrees of fineness. Among the appliances tried was a series of funnel-shaped vessels with the small ends downward, each fitted with an overflow lip. The bottom end of the funnel or cone-shaped vessel was fitted with a cap or plug discharging the contents into the next vessel of the series and so on. To each vessel was attached, near the bottom, a water pipe as well as a pipe carrying compressed air. The object of the water was to provide an upright current for the contents of the vessel, while the object of the compressed air was to produce agitation and enhance the agitation effect of the upcurrent of water with the expectation of reproducing the conditions causing the float or metallic froth. These experiments were on the lines of a spitzkasten with a strong upward current to produce an agitation on the slime water, assisted by jets of compressed air. It was thus early recognized that the bubbles of froth noted in the wet concentration operation were due to the aeration produced by violent agitation, resulting from mechanical implements moving rapidly in water. In these experiments a metallic froth or scum could be produced and recovered assaying 36 oz. silver, 30% lead, and 22% zinc.

Early Flotation Experiments.—Early in 1903 an exhaustive series of laboratory tests was made on the lead byproducts by flotation methods, using heated sulphuric acid and salt-cake solution. These tests yielded some success on materials specially prepared, that is on grainy material from which both the coarse and the fine had been eliminated, leaving it evenly sized. Certain classes of the material produced by the mills contained such a large proportion of carbonates—such as carbonate of manganese, lime, and lead—that no flotation could be secured except by a prohibitive consumption of acids. These tests were carefully made but the best work done in the laboratory was not equal to that being secured on a commercial scale in the existing magnetic plants. The testing of flotation

methods were conducted in pans or vessels worked on the principles of spitzkasten, following the lines of Potter and Delprat. The first apparatus was constructed so that the liquids could be raised in temperature by the application of direct heat underneath the pan, but in the later types the temperature of the liquor in the pan or spitzkasten was maintained by the injection of live steam into the storage tank. In none of these tests was agitation employed, the material to be treated being fed practically dry on the surface of the liquor in a regular stream and heated liquor added through a pipe discharging near the bottom of the vessel. A still surface was imperative in this operation and it was equally evident that the operation depended largely for success upon the surface tension of the liquor after the gas evolved by the action of the acid on the mineral carbonates had raised the particles. This surface tension was increased by the density attained in the one case by the salts formed from the mineral and gangue through the action of sulphuric acid and the other by the addition of salt-cake. In all of these experiments the liquor was returned by the ordinary type of air-lift, using compressed air at about 70 lb. pressure.

Experiments definitely demonstrated that there was a limit to the size of the particle that could be buoyed up. Also that any material below a certain size, no matter what its character—whether gangue or mineral—floated because of the density of the solution. And in addition, that if the finer particles of gangue were not eliminated before treatment they would be floated with the minerals and lower its value in metals to such an extent as to make it unmarketable. Slime, whether existing as a by-product of the ordinary wet-mill concentration or subsequently produced in preparing tailing for treatment, forms such a large part of the material available for treatment that any process that failed in this direction was too limited in its scope to be of value to the Central Mine.

As far as any process up to date was concerned slime had to be regarded as of no value except in so far as it was available for smelting. The Broken Hill Proprietary Co. had used a considerable quantity in this way and had discovered that roasting or sintering this slime in open heaps gave a fair product valuable for smelting, a good deal of the sulphur and a fair

proportion of the zinc having been driven out. The Sulphide Corporation also sought to make its slime available by this means, but it was proved that the losses of metal were too great to justify the method.

These experiments were abandoned and tests were made then on the Cattermole process. This process seemed applicable and a plant was constructed to take advantage of its principles. The plant ran a few months on tailing and slime from various sources and during this time the frothing method was generally ousting the granulation process, until finally the superiority of the froth method was clearly demonstrated. The froth method, thus, was a direct outgrowth from the granulation process at the Central Mine. The Wilfley tables of the original plant were then dismantled to make room for the sand boxes and the granulation process gave way to flotation with simple spitzkasten.

Introduction of the Froth Method.—Finally Minerals Separation, owners of the froth patent, purchased the tailing dump on the Central mine and by arrangement a plant was designed and erected by the Sulphide Corporation for their treatment. This plant was designed on previous experience for the treatment of 2,000 tons per week. It was finished at a cost of £26,000 complete. The efficiency of grinding pans proved so great with the new design of positive pan that the plant was easily able to handle 5,000 tons per week. This plant was responsible for the treatment of 7,999 tons of tailing and the production of 242,462 tons of concentrate up to the time it was shut down in June, 1911, upon exhaustion of the dump.

In connection with the Minerals Separation plant, it is important to note that the fact of the circuit being no longer acid, but neutral, has been taken advantage of, inasmuch as there is only one circuit through from grinding pans, agitators, and spitzkasten. The original granulation plant, being designed for acid circuits, was equipped originally with wood throughout where liquor circulated, and with dry-crushing ball mills for the same reason. Later, wet crushing was adopted, but with a fresh-water circuit, kept carefully separate from the acid circuit in which the actual separation took place. The successful development of the flotation process, however, has enabled both crushing and separation to be conducted in one

and the same circuit and has thus greatly simplified operations.

The liquor that was circulated through the Minerals Separation plant was approximately 25,000 gal. per hr. During the course of operation, therefore, nearly 3,000,000 tons has passed through the twelve iron grinding pans of this plant without detrimental effect. No stronger evidence could be produced as to the freedom of the circuit liquor from acidity. The maintenance charges on these iron pans are no heavier than corresponding charges on exactly similar grinding pans in the lead mill crusher section, where fresh water only is used.

Selection of the Oily Agents.—Following exhaustive experiments in the laboratory various media have, from time to time, been used for long periods on the commercial scale, both in substitution for and in combination with oleic acid. Chief among such media are amyl alcohol, resin oil, camphor, pine oil, and eucalyptus, with all of which ingredients good work has been accomplished. It was in the milling plant on the Central Mine that eucalyptus oil was first used on a commercial scale for concentration by flotation.

This satisfactory stage having been reached, attention could be turned to improvements in methods of handling, and on suggestions from the owners of the patents it was found that by connecting the bottom of each spitzkasten with the bottom of the next mixer in series, all of the spitzkastens could be kept on one floor, thus improving the supervision of the work. An experimental plant of this nature was erected at the end of No. 2 section in September, 1910, and, proving highly successful, the system was altered to that method of working. Experience shows that for ideal work the feed material should all pass through 40 mesh, but it is impossible to secure this condition of grinding at all times in the mill as designed. Moreover, although the Sulphide Corporation was aware that improvements in character of plant and methods of operation were easily possible, their attention, by force of circumstances, had to be turned sedulously to increasing the production with the appliances at hand,

Grinding for the Flotation Process.—Illustrating what is meant by ideal grinding, the records of the average assays of residues show continuously that where the average in zinc is from 2 to 2½%, that proportion remaining on 40 mesh will

assay from 3 to 4% zinc. As illustrating the character of feed, and proving that the process is capable of handling successfully the very finest material, sizing analyses by commercial screens of the feed to the zinc section, zinc concentrate as shipped, and de-leading plant lead concentrate as shipped, are given in the accompanying table.

Feed to Zinc Section.			Zinc Concentrate.			De-leading Lead.		
Through	On	%	Through	On	%	Through	On	%
	40	11.2		40	1.5		40	1.9
40	60	21.4	40	60	16.9	40	60	7.5
60	80	19.4	60	80	21.1	60	80	15.8
80	130	15.6	80	130	21.7	80	130	18.8
130	180	7.3	130	180	7.4	130	180	8.5
180		25.0	180		31.4	180		47.5

For comparison with the work at the old mill, the following summary of results achieved by the existing plant will be of interest. This table summarizes work done on a commercial scale at the Central Mill over a period of twelve months, ending December 28, 1912, and demonstrates conclusively the vast improvement in concentration practice made possible by the adoption of the flotation process.

SUMMARY

	Assay value.				Recoveries.		
	Prop., %	Ag, oz.	Pb, %	Zn, %	Ag, %	Pb, %	Zn, %
Lead concentrate ex lead section	16.0	33.1	67.0	6.7	44.7	72.4	6.1
Lead concentrate ex de-lead plant	1.4	50.9	62.5	12.5	5.9	5.8	1.0
Total lead concentrate	17.4	34.5	66.7	7.1	50.6	78.2	7.1
Zinc concentrate	32.7	16.1	8.1	46.4	42.1	15.9	84.7
Total concentrate	50.1	...	...	...	92.7	94.1	91.8

The Silver Peak Mill.—An article by H. Hardy Smith * describes another successful application of flotation in Australia. This small mill was erected at the Silver Peak mine for the purpose of treating the second-grade ores of the Yerranderie silver-lead mining field, New South Wales, Australia. Owing to the distance of the field from smelting works and the high cost

* *Eng. and Min. Journal*, Dec. 11, 1915.

of transport, over bad roads by horse teams, only the richest ores could be shipped at a profit. The question of smelting locally was studied, but owing to the highly siliceous nature of the "seconds" (about 70% SiO_2) and the difficulty of procuring suitable fluxes, the idea was abandoned. The question of concentration was then considered, the problem proving to be a difficult one. The metallic minerals in the ore were, in order

FIG. 24.—THE SILVER PEAK MILL, YERRANDERIE, NEW SOUTH WALES, AUSTRALIA.

of importance: Galena, pyrite, marcasite, arsenical pyrite, blende, chalcopyrite, and small quantities of secondary minerals from all the foregoing.

All these minerals carried silver to a greater or lesser extent, but the chief silver-bearing constituents were the galena, and the iron sulphides, especially the marcasite. The galena occurred in two crystalline forms, one coarse and the other fine, the latter having a fracture similar to hard cast iron. This was rich in silver. Being extremely soft and friable, it slimed badly on crushing. Some of the ore contained it in such a fine state of dissemination that it appeared as a dark streak through the quartz, necessitating very fine grinding to free the values. The gangue was chiefly a hard glassy quartz with small quantities of felsitic country rock. From this description of the ore it will be readily understood that concentrating it was not simple.

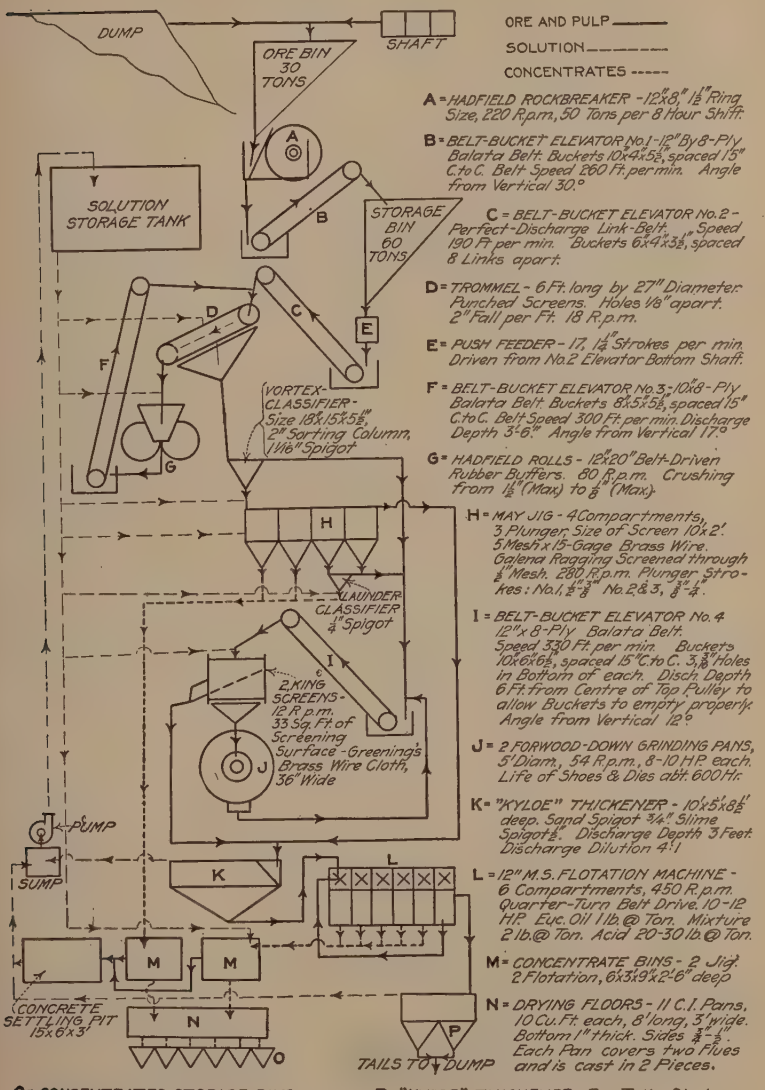

DUMP
ORE BIN 30 TONS
SHAFT
ORE AND PULP
SOLUTION
CONCENTRATES
A = HADFIELD ROCKBREAKER - 12"x8", 1½" Ring Size, 220 R.p.m., 50 Tons per 8 Hour Shift.
B = BELT-BUCKET ELEVATOR No.1 - 12" By 8-Ply Balata Belt. Buckets 10x4x5⅝, spaced 15" C.to C. Belt Speed 260 Ft. per min. Angle from Vertical 30.°
SOLUTION STORAGE TANK
STORAGE BIN 60 TONS
C = BELT-BUCKET ELEVATOR No. 2 - Perfect-Discharge Link-Belt, Speed 190 Ft. per min. Buckets 6x4x3½, spaced 8 Links apart.
D = TROMMEL - 6 Ft. long by 27" Diameter. Punched Screens. Holes ⅛" apart. 2" Fall per Ft. 18 R.p.m.
E = PUSH FEEDER - 17, 1¼" Strokes per min. Driven from No.2 Elevator Bottom Shaft.
F = BELT-BUCKET ELEVATOR No.3 - 10"x8 - Ply Balata Belt. Buckets 8x5x5⅝, spaced 15" C.to C. Belt Speed 300 Ft. per min. Discharge Depth 3'-6" Angle from Vertical 17.°
(VORTEX-CLASSIFIER - Size 18"x15"x5⅝", 2" Sorting Column, 1 1/16" Spigot
G = HADFIELD ROLLS - 12"x20" Belt-Driven Rubber Buffers. 80 R.p.m. Crushing from 1½" (Max) to ⅜" (Max).
H = MAY JIG - 4 Compartments, 3 Plunger, Size of Screen 10'x 2' 5 Mesh x 15-Gage Brass Wire. Galena Ragging Screened through ¼" Mesh. 280 R.p.m. Plunger Strokes: No.1, ⅜"-⅜" No.2 & 3, ⅜"-¼".
LAUNDER CLASSIFIER ¼" Spigot
I = BELT-BUCKET ELEVATOR No. 4 12" x 8-Ply Balata Belt. Speed 330 Ft. per min. Buckets 10x6x6⅝, spaced 15" C.to C. 3⅛" Holes in Bottom of each. Disch. Depth 6 Ft. from Centre of Top Pulley to allow Buckets to empty properly. Angle from Vertical 12.°
2 KING SCREENS - 12 R.p.m. 33 Sq. Ft. of Screening Surface - Greening's Brass Wire Cloth, 36" Wide
J = 2 FORWOOD-DOWN GRINDING PANS, 5' Diam., 54 R.p.m., 8-10 H.P. each. Life of Shoes & Dies abt. 600 Hr.
PUMP
SUMP
K = "KYLOE" THICKENER - 10'x5'x8½' deep. Sand Spigot ¾" Slime Spigot ⅝. Discharge Depth 3 Feet. Discharge Dilution 4:1
L = 12" M.S. FLOTATION MACHINE - 6 Compartments, 450 R.p.m. Quarter-Turn Belt Drive. 10-12 H.P. Euc. Oil 1 lb. @ Ton. Mixture 2 lb. @ Ton. Acid 20-30 lb. @ Ton.
M = CONCENTRATE BINS - 2 Jig, 2 Flotation, 6'x3'9"x2'6" deep
CONCRETE SETTLING PIT 15'x6'x3'
N = DRYING FLOORS - 11 C.I. Pans, 10 Cu. Ft. each, 8' long, 3' wide. Bottom 1" thick. Sides ⅜-½". Each Pan covers two Flues and is cast in 2 Pieces.
TAILS TO DUMP
O = CONCENTRATES STORAGE BINS - 50 Tons. Fitted with Chutes for Bagging.
P = "KYLOE" THICKENER - For Tails Discharge about 40% Moisture.

FIG. 25.—THE FLOW SHEET OF THE SILVER PEAK MILL.

Experiments were first made with gravity concentration, but the recoveries, especially of the silver, were low. The coarsely crystalline galena presented no difficulties, being amenable to jigging and table concentration; but this type was relatively low in silver, and the fine-grained variety, carrying the greater part of the silver, slimed so badly that no system of gravity concentration could give satisfactory recoveries. Flotation concentration was therefore tried, and as good results were reported from small-scale tests made by Minerals Separation, a plant incorporating that process was decided upon.

The average assay of the ore to be treated was about 30 oz. silver 10% lead and 1 to 2 dwt. gold per ton. Because of the excessive transportation charges, the aim was to recover as much as possible of these metals in the form of high-grade concentrates. As the orebodies on the field were narrow and limited in extent, the company desired a mill of small capacity (about 50 tons per day) and small capital cost, which proviso precluded anything of an elaborate nature in the design. Several thousand tons of "seconds" had been mined during the opening up of the high-grade shoots of ore and lay awaiting treatment. The plan was to get the mill started and "tuned up" on this ore, supplementing it with ore from current development and, on results proving satisfactory, to mine the second-grade ore on an extensive scale. The flow-sheet of the mill as erected is shown in the drawing, Fig. 25.

The thickener before the flotation machine was of the inclined-baffleboard type already described.* They are cheap to build and simple and efficient in operation. The clear overflow from the thickener ran to the pump sump. The thickened underflow ran to a 6-compartment, 12-in. standard Minerals Separation machine. The tailings from the Minerals Separation machine ran to another thickener, the clear overflow from which ran to the pump sump, and the thick overflow into trucks and thence to the dump.

Handling the Concentrates.—The flotation concentrates ran to a pair of bins, one being filled while the other was settling and being emptied. The turbid overflow from these bins ran to a concrete-lined pit where it was allowed to settle completely,

* "Flotation Process at Kyloe, N. S. W.," *Eng. and Min. Journal*, Dec. 7, 1912.

the clear overflow from the pit running to the pump sump. This pit was cleaned out at intervals. After siphoning off the excess water from a concentrates bin, the sloppy concentrates were shoveled onto cast-iron drying floors and when dried sufficiently, into bins which fed chutes leading to the bagging floor.

The jig concentrates were handled similarly. On starting up the plant, the first serious difficulty encountered was in the

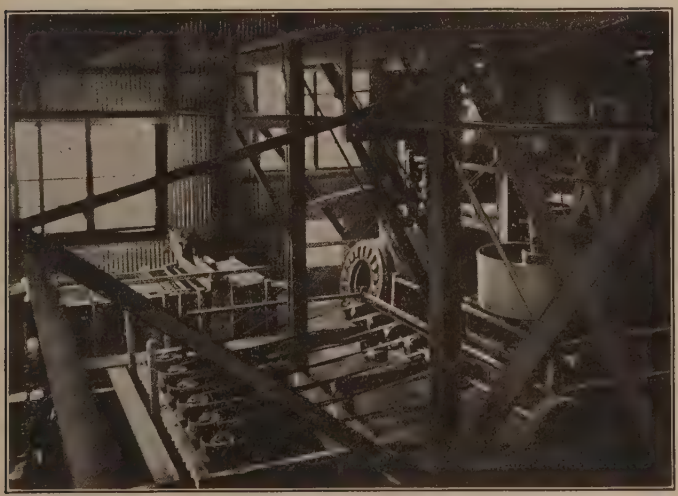


FIG. 26.—GRINDING PANS, THICKENER, AND TOP OF MINERALS SEPARATION FLOTATION UNIT AT THE SILVER PEAK MILL.

regrinding section, which could not handle the tonnage, when grinding to the degree of fineness required for good work in the flotation section. With the idea of lightening the load on the pans, the rolls were set hard up with considerable pressure between them so as to act by choke crushing. This increase in the quantity of slimes produced was immaterial owing to the ability of the flotation plant to handle this product efficiently. This readjustment made some improvement, but not sufficient to make up the leeway, and finally coarse screens had to be put on the King screening machines, increasing the aperture from 0.015 in. to 0.024 in. This resulted in a product altogether too

coarse for good work at the flotation section, a point which must be kept in mind when considering the results.

The pulp as it left the regrinding section had a dilution of about 15 to 1 and before being treated at the flotation plant this was reduced to 4 to 1 in a Kyloe pulp thickener, the surplus water being returned by pump to the mill-water supply tank.

The treatment at the Minerals Separation flotation plant involved the use of heat, acid and two oils. *Eucalyptus amygdalina* was used as an emulsifying agent and a dark lubricating-oil mixture to maintain the froth. The pulp was heated to 120° F. by live steam introduced into No. 1 agitating box. The consumption of steam was heavy, being equivalent to about 10 hp. (non-condensing) even when the initial temperature of the pulp was kept at about 90° F. by passing some of the mill water through the engine condenser.

The consumption of the different kinds of reagents varied considerably with the different kinds of ore, but the average was about as follows: Acid, 20 to 30 lb. per ton; *eucalyptus amygdalina,* ¾ to 1½ lb. per ton; mineral-oil mixture, 2 to 2½ lb. per ton. The sequence and method of using the reagents had to be altered from time to time to overcome difficulties that cropped up in the treatment.

Necessity for a Clean Water-Supply.—One of the early difficulties encountered was of a peculiar kind and is well worth recounting. The water-supply for the mill was drawn from a dam, fed partly by surface drainage and partly by water from the mine. For four years previous to the commencement of milling operations this water supply had not been drawn on and had simply evaporated and soaked away. A few days after starting the plant the water became discolored, first to a greenish yellow, then through yellow to a brick red. As soon as this reddish water arrived at the flotation plant the process went out of commission. The trouble seemed to be a total absence of aëration, which no amount of eucalyptus oil or other reagent could remedy. As much as 50 c.c. of eucalyptus oil was added to No. 1 agitating box at one time without producing any real froth or any signs at the back of the flotation spitz of the violent ebullition that is characteristic when the machine is in good working order. Occasional "blobs" of air came to the surface but nothing in the shape of a froth.

The red discoloration was due to a fine precipitate which on analysis seemed to be basic sulphate of iron. The precipitate was soluble in excess of acid, but the consumption made this remedy impracticable. The trouble was finally overcome, partly by keeping the mill solution in closed circuit and partly by manipulation of the reagents. Even with the closed circuit the loss by evaporation and leakage amounted to about 5,000 gal. per shift and this had to be made up with mine water.

This method of working led to another difficulty in the shape of scale and incrustations which formed chiefly in the Minerals Separation machine, but also in the screens and settler. In the flotation spitz the deposit took the form of sponge-like masses of crystals, while in the agitating boxes, in spite of the strong scouring action of the impellers, it was like a bad boiler scale. Both types dropped off at intervals and blocked the valves and pipes in the machine. At one period the trouble became so acute that it looked as if the plant would be a complete failure. The deposits were first noticeable when the solution contained only 450 grains of salts per gallon of solution, and up to a certain point they increased with the density of the solution. The incrustation appeared to be fine sand and slime bound together with sulphate of lime and magnesia.

At the King screens the meshes of the wire cloth became badly blinded. After a week or ten days the screening area became so reduced that the screens could not handle the tonnage, so the wire cloth had to be removed and cleaned by pickling in a weak acid solution and then scrubbing with stiff wire brushes. The changing of the cloth on this type of screen is quite a tedious operation, and much time was lost thereby.

Samples of scale were assayed and showed in the deposit from the flotation spitz 61 oz. Ag and 14.5% Pb. and in the deposit from the agitating boxes 16 oz. Ag and 3.5% Pb. The residue after evaporating filtered solution assayed 4 oz. Ag and 1.2% Pb, showing that small quantities of both silver and lead were being dissolved.

Removing the Floating Froth.—The removal of the float from the surface of the flotation spitz presented another difficulty. When the machine was doing its best work the float was dense and heavy, being more of the nature of a thick scum than the usual frothy float composed of a fairly light mixture of

bubbles and coagulated sulphides. The usual method in a case like this is to use paddles, but here they were ineffective as the float would not feed forward under the paddles. If the paddles were run fast and dipped deep, so as to cause a forward suction, the slime was stirred up and overflowed the lips with the concentrate, making it low-grade.

To overcome the difficulty the device shown in Fig. 27 was put in. It consists simply of a pair of ropes traveling forward along both sides of the spitz. A ¾-in. pipe was run along the front of the spitz boxes, mounted on three simple bearings. To this pipe, 4-in. rope sheaves were keyed, two to each spitz. Along the back of the boxes a ¾-in. iron rod was run and another set of 4-in. sheaves threaded on and held in place by pins through the rod so that they could revolve freely without moving sideways. One-half-inch manila rope was spliced on over the sheaves. The ¾-in. pipe was driven at a very slow speed by a long rope from a slow-moving countershaft in the mill. Different-sized driving sheaves were kept handy so that the speed of the rope rabbles could be altered when necessary. It varied from 4 to 8 ft. per min. for the different classes of ore.

A coil of rope was kept handy, and a template was marked on a bench so that as the ropes wore they could be replaced rapidly by new ones. The ropes were put on with a rough long splice, and the men soon became expert enough to replace a rope in a few minutes. While one rope was out of business, the other did the work fairly well. Once the amount of shrinkage had been determined and allowed for, this characteristic of manila rope caused no trouble, its hairy nature made it effective, and this, combined with its low cost, made it preferable to rubber or composition bands. After about 12 months, the back sheaves had to be renewed.

If the surface of the water was kept within ¼ in. of the lips these rope rabbles would feed the float into the launder, but as this close regulation of the water level was difficult, very small paddles were mounted between the sheaves on the front pipe so as to dip just behind the lips and touch the froth over.

The assays of the floats from the various spitz boxes are shown in Table 2. The overflow from No. 6 spitz was always, and that from 4 and 5 sometimes, returned to No. 1 agitating box

for retreatment. A retreatment scheme for the whole of the concentrates in a separate machine, though highly desirable under the conditions, was not feasible—first, on account of the extra cost of plant and treatment, and second, because the

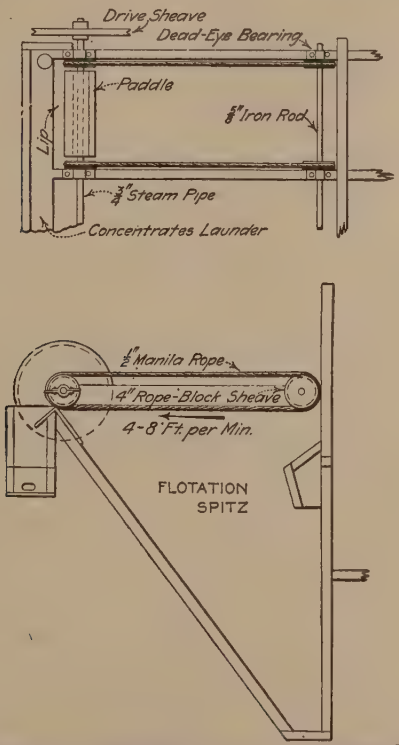


FIG. 27.—DEVICE FOR REMOVING FOAM AT THE SILVER PEAK MILL.

amount of concentrates produced (from 3 to 5 tons per 24 hr.) was not sufficient to keep a machine adequately supplied.

Washing Concentrates to Improve their Grade.—In spite of all precautions the bulk concentrate from the machine ran about 15% insoluble. To improve this a scheme for washing the concentrates in the settling bins was introduced. The bin was fitted with a number of inclined removable baffles, and behind

the first one a heavy spray of cold water was played on the float. This had the effect of disintegrating it so that the sulphides, still in the form of coagules, settled to the bottom at the same time a portion of the floated gangue was carried over a lip by the slow-moving current of water. The solids in the overflow assayed 50 oz. Ag, 10% Pb, and 70% insoluble.

The average value of the mill concentrates is shown in the table:

	Au, Dwt.	Ag, Oz.	Pb, %
In jig concentrates	6.0	69.4	21.5
In flotation concentrates	7.4	115.7	19.6

The mill tailings ran from 8 to 12 oz. Ag per ton, under 10 grains Au, and 2 to 2.5% Pb. The proportion of jig concen-

TABLE 1. GRADING ANALYSIS OF REGRINDING SECTION

Grades	Energy Unit	Feed		Discharge	
		Weight %	Total E.U.	Weight %	Total E.U.
—⅛ + 12	10.7	25.8	276.06	....	....
—12 + 20	15.0	24.2	363.0	....	....
—20 + 30	17.0	11.7	198.9	0.4	6.8
—30 + 40	18.0	6.6	118.8	4.0	72.0
—40 + 60	19.5	7.7	150.2	24.3	473.8
—60 + 80	21.0	4.0	84.0	15.5	325.5
—80 + 100	23.0	2.6	59.8	9.1	209.3
—100 + 150	24.0	1.4	33.6	4.9	117.6
—150	27.5	16.0	440.0	41.8	1,149.5
		100.0	1,724.4	100.0	2,354.5
					1,727.4
				Difference	630.1

Tons per 24 hr., 33.6.
Horsepower, 16.0.

$$\text{Efficiency} = \frac{630.1 \times 33.6}{16} = 13.2$$

TABLE 2. ASSAY OF OVERFLOWS FROM FLOTATION BOXES

Box No.	Silver, Oz. per Ton	Lead, %	Insoluble, %
1	158.0	25.6	9.3
2	132.7	23.2	10.8
3	134.0	23.0	10.7
4	130.0	22.0	15.7
5	123.0	21.5	18.5
6	49.0	9.0	50.6

trates to flotation concentrate was about 2 to 1. The recoveries for the whole mill averaged only about 70% of

TABLE III.—GRADING ANALYSES AT SILVER PEAK FLOTATION PLANT

Grades by I.M.M. Screens	HEADS 100 Tons (Assumed)							CONCENTRATES 5.8 Tons (from Average Assays)								TAILINGS 94.2 Tons (by Difference)									
	Weight of Heads %	Assay Values Ag, oz.	Assay Values Pb, %	Total Values per 100 Tons of Feed Ag, Oz.	Total Values per 100 Tons of Feed Pb, Tons	Per Cent. of Total Values in Feed Ag	Per Cent. of Total Values in Feed Pb	Weight of Concentrates, %	Weight per 100 Tons of Feed, Tons	Assay Values Ag, Oz.	Assay Values Pb, %	Total Values per 100 Tons of Feed Ag, Oz.	Total Values per 100 Tons of Feed Pb, Tons	Per Cent. of Total Value in Feed Ag	Per Cent. of Total Value in Feed Pb	Weight of Tails, %	Weight per 100 Tons of Feed, Tons	Assay Values Ag, Oz.	Assay Values Pb, %	Total Values per 100 Tons of Feed Ag, Oz.	Total Values per 100 Tons of Feed Pb, Tons	Per Cent. of Total Values in Feed Ag	Per Cent. of Total Values in Feed Pb	Recoveries Made on Each Grade. Ag, %	Recoveries Made on Each Grade. Pb, %
— 25 + 30..	0.4	12.0	1.5	4.8	0.006	0.24	0.2	0.5	0.003	120.0	27.0	0.36	0.001	0.018	0.032	0.4	0.37	12.0	1.4	4.44	0.005	0.22	0.17	7.5	13.3
— 30 + 40..	5.1	13.0	1.6	66.3	0.082	3.4	2.7	0.7	0.042	121.0	26.0	5.1	0.011	0.25	0.36	5.0	4.71	13.0	1.5	61.33	0.071	3.10	2.31	7.6	13.6
— 40 + 60..	28.4	11.5	1.6	326.6	0.448	16.5	14.7	4.0	0.238	115.0	31.7	27.4	0.116	1.39	3.81	29.4	27.69	10.8	1.2	299.16	0.332	15.16	10.93	8.1	25.9
— 60 + 80..	20.4	14.2	1.7	289.7	0.347	14.7	11.4	6.3	0.365	150.0	26.8	54.7	0.098	2.77	3.22	24.0	22.61	10.4	1.1	235.04	0.249	11.91	8.17	18.8	28.2
— 80 + 100..	9.4	17.3	1.8	162.6	0.169	8.2	5.6	8.0	0.470	204.5	10.0	96.3	0.047	4.88	1.54	10.8	10.18	6.5	1.2	66.30	0.122	3.36	4.02	59.2	27.8
— 100 + 150..	5.5	20.5	2.6	112.8	0.143	5.7	4.7	8.8	0.521	162.5	18.4	84.6	0.096	4.28	3.15	5.0	4.71	6.0	1.0	28.20	0.047	1.42	1.53	75.0	67.0
— 150	30.8	22.8	6.0	1010.2	1.848	51.2	60.7	71.8	4.172	190.0	31.6	792.7	1.322	40.17	43.48	25.4	23.93	9.1	2.2	217.49	0.526	11.02	17.29	78.4	71.5
Totals.....	100.0			1973.0	3.043	99.9	100.0	100.0	5.811			1061.4	1.691	53.76	55.59	100.0	94.2			911.86	1.352	46.19	44.42		
Average totals		19.73	3.04							182.6	28.4							9.68	1.44					53.8	55.6

(*Facing page* 167)

the silver and 75% of the lead. In considering these low recoveries it must be remembered that during the period under review the plant was operating under two great disabilities—first, the inadequate regrinding facilities, and second, the fact that during the whole time, except for a few days toward the end, the plant was operated only one shift of 8 hr. per day. To give an idea of the importance of the former, a complete grading analysis of the feed and products from the flotation plant is given in Table 3. In columns 25 and 26 the recoveries made on each grade are given. Note the low recoveries on the coarser grades. It is not until the —100 to +150 grade is reached that anything like respectable recoveries are effected. The heads which remain on 80 screen contain 687.4 oz. Ag (by addition in column 5). The corresponding tailings contain 599.8 oz. (by addition in column 21), which represents a recovery of only 12.7%. The heads which pass an 80-mesh screen contain 1,285.6 oz. Ag, while the corresponding tailings contain only 312 oz., which represents a recovery of 75.7%.

Had the whole of the heads been ground to pass an 80-mesh screen, the —80-mesh product would have been enriched by 687.4 oz., bringing the total up to 1,937 oz.; while, assuming that the extra tonnage of —80-mesh product would not affect the recovery made on that grade (if anything it should improve it), the —80-mesh tailings would be increased by 34.3% of 687.4 oz., or 235.8 oz., bringing the total loss in the tails up to 547.8 oz., which would give a total recovery of 72.2% of the silver.

The recovery under the existing conditions was only 53.8%, so that by grinding the whole of the feed to pass an 80-mesh screen the recovery would have been increased at least 18%, making the total recovery for the mill about 90% of the silver. Unfreed values were not altogether responsible for the losses due to the coarse crushing. Much of the free mineral itself was in pieces too large to be successfully floated. This was especially the case with the iron minerals and the finely crystalline galena. The large particles of coarsely crystalline galena appeared to float more readily. A good tailing of fairly coarse free mineral could be obtained by panning a sample of tailings which had been allowed to weather for some time so as to overcome the tendency of the sulphides to float off. So

that better recoveries could have been expected if the sands had been passed over concentrating tables before being treated at the flotation plant. It would probably prove more economical to crush fairly fine, say not more than 15% on 80-mesh, and to table the sands, than to crush the whole product through 80-mesh and rely exclusively on flotation for the recovery of the sulphides. But here again, at this mill, the limited capital available was the governing factor.

The Daly West Mill.—The new mill of the Daly West Mining Co., Pratt City, Utah, has been described by L. O. Howard.*

The mill, which went into commission in January, 1915, is housed in two structures, one 71 ft. long, 27 ft. wide and 60 ft. high from floor line to top of ore bins, housing the storage bins and the primary crushers. The mill is of the hillside type, the fall from the head of the mill proper to the tailing launders in the tunnel beneath the mill being about 70 ft. There are five levels. On the top are the receiving bins, on the floor below are two Franz jigs, above which are the feeding trommel and Akins classifiers. On the third floor are the roughing Wilfleys, Harz jigs, Sherman tanks and regrinding rolls. On the second floor are eight concentrating tables and the flotation plant, and on the first, the Harz tailing jig and concentrate launders. The accompanying flow sheet shows the simplicity of the plant.

Milling the Ore.—The second-class ore is drawn onto an 18-in. conveyor which delivers to bins at the top of the ore house. From the bins the ore is sent in belt feeders over 3 x 6-ft. grizzlies. A 10 x 20-in. Blake crusher takes the oversize and discharges it into a trommel which is 48 x 72 in. and covered with double-crimped wire screen having two meshes to the inch. A 24-in. belt conveyor then takes the oversize of the trommel to a 48-in. Symons disk crusher. The head pulley of this conveyor is magnetized to remove all pieces of steel from the feed. The discharge of the Symons crusher and the undersize from the trommel are taken from the ore house to the mill bins by a 24-in. Robins belt conveyor, 210 ft. long with 6° slope. There is a Blake-Denison weigher having a capacity of 30 tons per hr.

The ore is sampled as it falls into the bin by a box rotating on a vertical axis at the rate of one revolution in ten minutes.

* *Met. and Chem. Eng.*, Sept. 15, 1915.

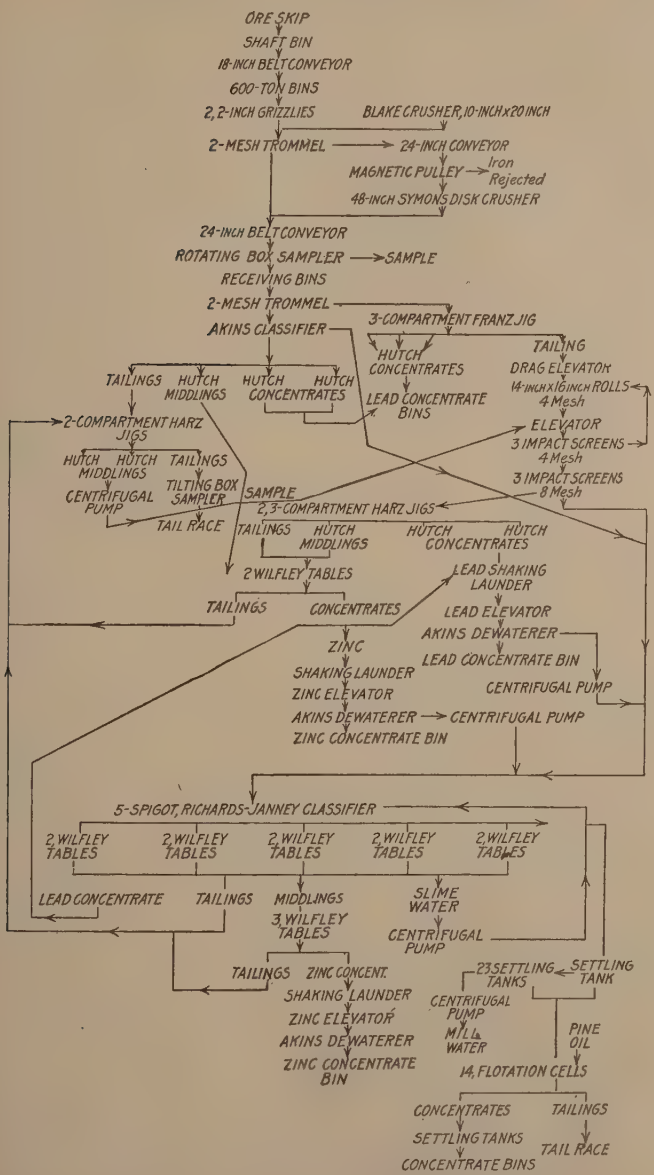


FIG. 28.—FLOW SHEET OF THE DALY WEST MILL, PARK CITY, UTAH.

From the bin the ore is fed into a 48 x 72-in. trommel covered with two-mesh screen and the oversize goes directly to one of two Franz jigs, the undersize going to the other after the slime has been removed in a 51-in. Akins classifier. The jigs are of the movable-screen type and are more often seen in the Missouri zinc district than in the West. There are screens 10 ft. long and 27 ft. wide. On the coarse jig the screen size is changed at intervals, the first two feet having 5/16-in. apertures, the next three feet having ½-in. apertures and the remainder being divided between screens having apertures of ⅝ in. and ¾ in. respectively. The fine jig has 2½ ft. each of 3/16-in., 1/4-in., 5/16-in., and 3/8-in. screens. The feed is divided into the proportion of 120 tons per day to the coarse and 80 tons to the fine. The coarse jig makes three finished hutch products averaging 30% lead which goes to the lead concentrate bin, The first two hutches from the fine jig are also finished products and will average about 35% lead. The third hutch of the fine jig goes to two Wilfleys which make a finished zinc concentrate and a tailing that is retreated on the Harz jig on the lowest level of the mill. Tailing from the coarse jig is reground in 14 x 36-in. rolls and is elevated to a series of two sets of three impact screens where three sizes are made; on 4 mesh, through 4 mesh, on eight mesh and through 8 mesh. The coarse is returned to the rolls. The middle size is treated on two three-compartment Harz jigs that make two finished hutch-concentrate products and a third hutch and tailing that are retreated on the same Wilfleys that receive the third-hutch product from the fine Franz jig. The undersize joins the slime from the Akins classifier and from the later table treatment, and is classified in a five-spigot Richards-Janney classifier. Each spigot feeds two Wilfley tables, the oversize after thickening going to the flotation plant.

The ten Wilfleys make similar products, a finished lead, concentrate, tailing and middling, which is retreated for a finished zinc concentrate and a tailing on three Wilfleys, and head water which is returned to the classifier. The concentrate from the Harz jigs and Wilfley tables drop to separate lead and zinc launders suspended on hangers running across the width of the mill in a tunnel on the lowest level. The head end of the launders is connected with a shaking device that causes the

concentrate to flow to two sets of elevators in series, which discharge into two Akins dewaterers, the drained concentrate dropping into lead and zinc bins. They are then trammed in one-ton cars through a tunnel to a sub-level of the ore house and are then elevated on a cage to the conveyor shed connecting shaft and ore house and trammed to the shaft. They are then lowered to the 1,200-ft. level and hauled out through the Ontario tunnel to Park City where they are loaded on wagons and hauled to the sampling works.

Flotation Applied to Slime.—The feed to the flotation plant consists of slime from the Richards-Janney classifier, which is thickened in one large and 23 small settling tanks of the type used in the old mill. The unit consists of two mixing cells and 14 flotation cells having a capacity of 30 tons of dry slime per day. The type is similar to that used by the Federal Lead Co. Each cell is 4 ft. 4 in. long by 20 in. wide and 5 ft. 8 in. deep at the tailing-discharge ends. They are set side by side with the sides in common. The shape of the cells is indicated diagrammatically in the accompanying sketch. The slime is fed into the first mixing chamber where it is mechanically agitated by a vertical propeller driven by a belt from a line shaft extending the length of the unit. From this compartment it is drawn into a second similar one and then into a third, which is part of the first flotation cell. Each flotation cell has two compartments, one similar to the mixing cells and another larger one where the flotation is effected. A flotation concentrate is taken off each cell, the tailing passing through the whole system of cells in series.

The propeller in one cell draws the tailing from the bottom of the preceding flotation compartment and discharges through a slot in the top into its own flotation compartment. The froth floats to the opposite side of the flotation compartment and is skimmed off by a paddle wheel that drops it into the concentrate launder where a jet of water breaks up the froth. The concentrate flows to a centrifugal pump that lifts it to an elevator delivering it to concentrate bins. This concentrate is marketed as a lead product.

The tailing settles to the bottom edge of the flotation compartment and is drawn into the next cell and again subjected to flotation, until it has passed the final cell when it goes to the

tailing discharge. Flotation tailing is sampled by dipper. The weight of the material treated is ascertained by specific-gravity determinations made on a large sample caught during

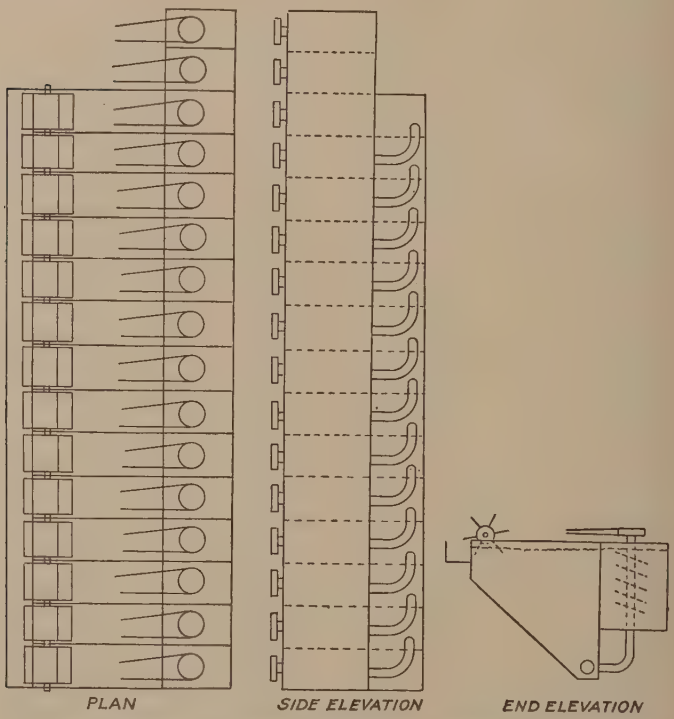


Fig. 29.—Diagram of Flotation Apparatus at the Daly West Mill.

a definite period. Pine oil is introduced drop by drop into the first mixing cell. The consumption of oil is said to be about 50 gal. per month, which is equivalent to about 0.4 lb. per ton of slime treated.

The mill is operated one 8-hr. shift daily with a force of 15 men, and treats 200 tons per shift. Operations are controlled by means of the data obtained at the following points: The weight of ore fed to the mill is obtained from the Blake-Denison

weigher, and the analysis of the feed is made on the sample taken at the end of the conveyor belt that brings the crushed ore to the mill from the crusher or ore house. Weight of concentrate is known and analyses are made on samples taken by pipe sampler from each car as it is taken from the concentrate bin. Analyses of tailing are made on the sample taken by tilting-box sampler from the discharge of the tailing jig. The tailing from the flotation department, which does not go to the tailing jig, is sampled by dipper and the weight obtained by specific-gravity determinations made on pulp discharged for a known period. Regular samples are not taken during the course of ore through the mill, but in case of any irregularity in the general tailing assay, the suspected machines are subjected to check sampling in order to remedy the trouble.

The compact flotation system has replaced the complicated classification and retreatment of slime and has done away with 12 slime tables. There still remain a large number of dewatering tanks preceding the flotation tanks which are used to thicken the feed to it.

CHAPTER X

FLOTATION OPERATING PLANTS

The flotation process, either with or without oil, is now operating either experimentally or commercially in almost every mining camp in the United States and Canada. A large number of plants have adopted flotation, either as a principal proc-

FIG. 30.—MILL OF THE NATIONAL COPPER CO., NATIONAL, IDAHO.

ess or as an auxiliary, and with many others it is only a question of a short time when the process will be utilized as a step in the scheme of metallurgy. It would be hopeless to attempt to explain the procedure at all operating plants, but it will be of interest to outline the methods followed at some of the important and successful works to which flotation has proved a valuable aid.

National Copper Co.—The National Copper Mining Co.'s mill, near Mullan, Ida., contains the first commercial, large-scale application of the Callow pneumatic flotation system. In this plant, stage grinding, table concentration, regrinding,

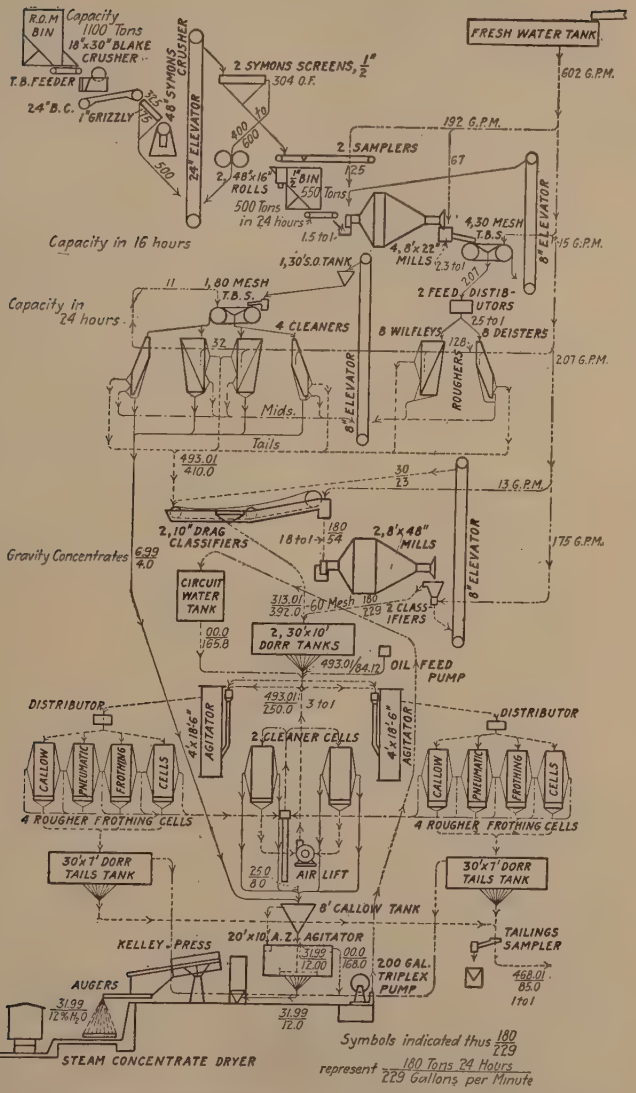


FIG. 31.—FLOW SHEET OF THE NATIONAL COPPER MILL, NATIONAL, IDAHO.

and flotation concentration is practiced. The accompanying flowsheet shows the details of the practice followed. Other plants using the Callow process are the Inspiration Consolidated

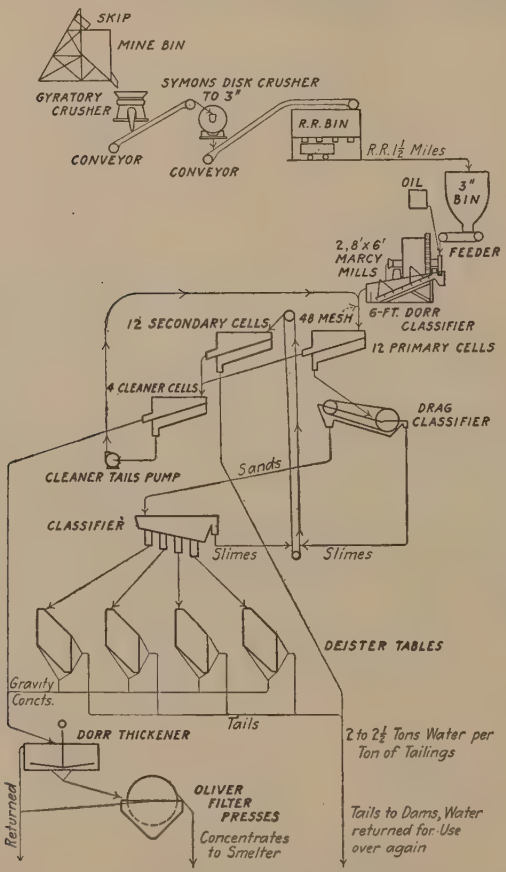


FIG. 32.—FLOW SHEET OF THE INSPIRATION MILL, ARIZONA.

Copper Co., the Arizona Copper Co., and the Daly-Judge. The flow sheets of these mills, as published by J. M. Callow,* are

* "The Callow Pneumatic Flotation Process," A. I. M. E., Feb., 1916, meeting New York.

shown herewith, giving a comprehensive idea of how the process is carried out at these mills.

A plant at the Iowa mine, in Colorado, has also installed the Callow type of flotation machine. The box is 2 ft. 4 in. by 9 ft. inside, the slope of the diaphragm compartment bottom is 4 in.

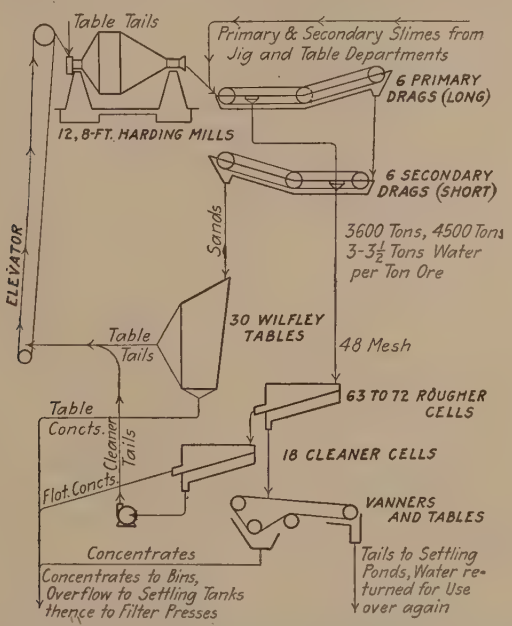


Table Tails
Primary & Secondary Slimes from Jig and Table Departments
6 PRIMARY DRAGS (LONG)
12, 8-FT. HARDING MILLS
6 SECONDARY DRAGS (SHORT)
ELEVATOR
Sands
3600 Tons, 4500 Tons 3-3½ Tons Water per Ton Ore
30 WILFLEY TABLES
Table Tails
48 Mesh
63 TO 72 ROUGHER CELLS
Table Concts.
Cleaner Tails
18 CLEANER CELLS
Flot. Concts.
VANNERS AND TABLES
Concentrates
Concentrates to Bins, Overflow to Settling Tanks thence to Filter Presses
Tails to Settling Ponds, Water returned for Use over again

FIG. 33.—FLOW SHEET OF THE ARIZONA COPPER CO.'S PLANT AT MORENCI, ARIZ.

to the foot. There are seven compartments into which hoses lead from the air line. The sand discharge is regulated by a cock, but will be changed to a plug, the wear being excessive on metal parts. The water level is regulated by a short pipe turning on a loose elbow in a separate box on the discharge end of the machine. The air line pressure is about 6 lb. per sq. in. The mill practice provides for primary crushing in a Blake crusher, then through rolls and jigs (¾ of the concentrate product is drawn off the screen on hutches). Jig tailings are

dewatered by a screw conveyor and are all sent to the chilean mills and crushed through a 30-mesh screen. This product is classified and sent to concentration tables. The middlings are separated in spitzkasten and returned to one table for retreat-

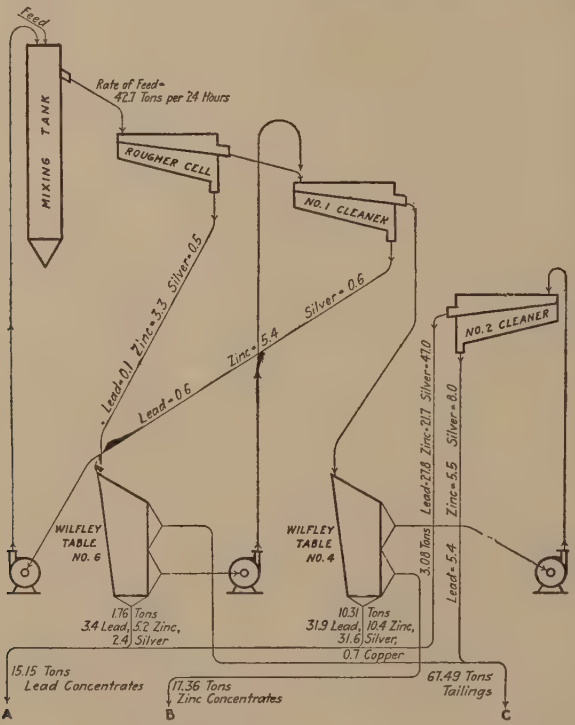


FIG. 34.—FLOW SHEET OF THE FLOTATION INSTALLATION OF THE DALY-JUDGE MILL.

ment. The slimes all go to a large settling box, where the top is skimmed and a flotation product is taken below the top. This passes to a pump where oil is introduced and then into the feed box on a machine.

Pine oil and creosote are used. Pine oil alone will work on some of these ores, while on others an excess of pine oil is detrimental, but creosote will work very satisfactory alone. The

ore treated at the Iowa mill comes from Silver Lake basin and is the result of extraction by lessees on the Iowa and Silver Lake mines.

Gold King and Atlas Mills.—At the Gold King mill the whole plant is now on a flotation basis and is doing excellent work along the lines laid out before, which may be seen from the accompanying flow sheet. At Ouray, the Atlas mill is crushing through a gyratory breaker first to 2½ in., then through stamps, 1,500 lb. using 12-mesh screens, and then to Callow cones. The spigot product goes to Wilfley tables with special riffles, while the overflow goes to the flotation department. There are two Callow cones which thicken to 50% material which is then reground in an 8-ft. by 22-in. Hardinge mill, the discharge going to another two Callow cones, from which the spigot portion is taken to Wilfley tables again, and the overflow to flotation. Concentrates from the table go through a drier and are shipped. The flotation machines are of the Minerals Separation type, in which the froth from the first and second cells go into the concentrates. Froth from the last five compartments is skimmed and returned through the machines.

The discharge from the flotation goes to launder-type classifiers from which the overflow is taken to tailings and the spigot product to Deister sand tables that make dirty concentrates. They take everything up to 50% silica, and this is all put over the Wilfley table. This last step is used as an indicator to ascertain what the flotation plant is doing, the result showing up readily on the table deck. The oils used are fuel oil, pine oil, and pine-tar oil in the ratio of three parts, two parts and one part, respectively. No. 1 can be replaced by any light lubricating oil; the mill has successfully used winter black. No. 2 can be replaced by turpentine and No. 3 by creosote. An interesting feature has developed in the use of these oils. They formerly mixed up a supply for one day only. At one time an over-supply was mixed by accident and allowed to stand. On using this combined oil an increase in efficiency was immediately noted. The explanation which has been made is that fuel oil and pine oil, or turpentine, by some chemical action precipitates free carbon which breaks down the froth. For this reason its efficiency is increased by standing whereby the

carbon is precipitated, and now they mix a week's supply at one time. Trouble is experienced with colloidal silica, and, for this reason, the tailings from flotation must be set over tables.

The Oneida Stag Mill.—A recent article * by R. W. Smith shows the practice followed by the plants where cyaniding was displaced by the flotation process. This is at the Oneida Stag Mines and Mill Co., at Idaho Springs, Colo. The ore is said to be typical of the Idaho Springs district. It has been milled for the gold and silver contained in pyrite, gray copper, chalcopyrite, and a little galena. In the early days, the ore from the mine was high grade, and was then stamped, amalgamated, and concentrated. Various systems of metallurgy were tried at this plant for many years, but thoroughly satisfactory results were not obtained until after experiments had been made on flotation, which finally replaced the cyanide process formerly operating at the mill.

After a thorough season of experiments the cyanide part of the mill was changed into a flotation plant. The accompanying drawing indicates the flow sheet of the original cyanide plant and of the flotation plant replacing it. The Dorr thickener and Dorr classifier shown were both part of the cyanide plant and fitted perfectly into the flotation scheme. The flotation machine itself was built in Denver and shipped in one piece to Idaho Springs. Two weeks after it arrived the feed was turned in, and in a little over three weeks it was making a commercial profit.

The entire tailing from the table floors is run through the Dorr classifier, which eliminates the coarse sand. This is advantageous because the coarse sand contains practically no value, only about 14c. in gold and 15c. in silver, and by removing it, the wear of the flotation machine is considerably reduced. After removing the sand, the slime is conducted to the Dorr thickener, as shown, where it is dewatered. The thickened pulp, as discharged from this machine, is elevated to a small box near the first cell of the flotation machine by means of a diaphragm pump. From here the feed enters the flotation machine. The oil is added at this point, but neither acid nor heat is necessary in the treatment.

The flotation machine has eight cells, or compartments, con-

* "Flotation Replaces Cyanide," *Eng. and Min. Journal*, Jan. 15, 1916.

nected in series, through which the pulp is made to flow by an external method of circulation of special design. The agitation is accomplished by a double agitator driven by a quarter-turn belt for each cell. The agitators in each cell turn in the same direction, since they are both fastened on the same shaft, but the blades are turned at such an angle that one impeller opposes the action of the other. The peripheral speed of the impeller is about 1,500 ft. per min. The agitator cells are 18 in.

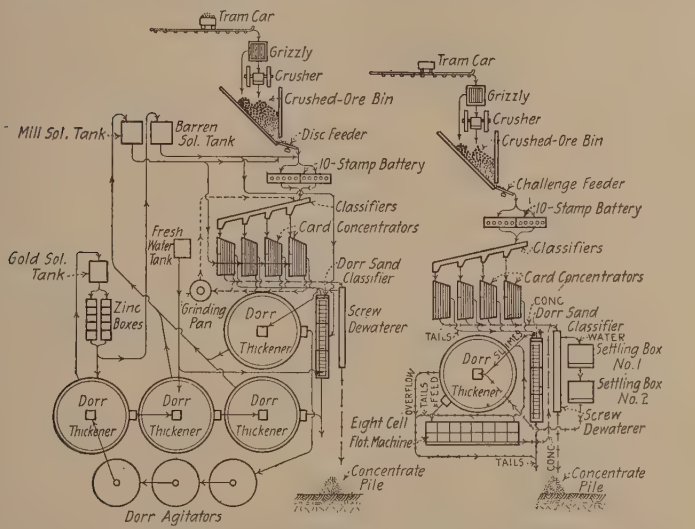


FIG. 35.—FLOW SHEETS OF THE CYANIDE PLANT AND THE FLOTATION PLANT INTO WHICH IT WAS CHANGED.

across inside the lining. The tailing discharged from the eighth cell is reconducted to the Dorr thickener in which the slime from the sand classifier is thickened. This is an innovation that increases the recovery materially.

Handling the Concentrate Froth.—The froth from all eight cells is conducted to a screw dewaterer, into which is also conducted the table concentrate. This is advantageous because the table concentrate is coarse and stacks easily and is readily handled. If a special product is made of the flotation concentrate, an expensive dewatering system is required and it may

involve an expensive filter press. With the mixing system, the froth goes directly with the table concentrate into the dewaterer. A total of 100 lb. of slime concentrate per hr. is the amount delivered by a flotation machine. The dewaterer removes about 2/3 of the total tonnage of the slime, with the coarse concentrate. The outflow from the dewaterer carries away the other which is then led to two large settling boxes.

The overflow from the second settling box is led back to the Dorr thickener, thus forming a closed circuit and none of the concentrate is lost. Nearly all of the remaining third of the slime concentrate that overflows the dewaterer settles in the settling boxes. The insoluble material raised with the mineral is considerable—about 16% in the first cell and about 30% in the eighth, or last cell, making an average of about 24%. There is only a slight penalty for this, and therefore there is not much objection to it. The table concentrate is much cleaner, and averages about 9% insoluble. After mixing in the flotation concentrate, the total product averages about 16% insoluble, an amount for which the penalty is quite low.

Table concentrate assays about 1½% copper, and as the buyers do not pay for less than 1½%, the amount is lost. The flotation concentrate, however, runs about 3½ to 4% in copper, and an increased profit was believed to be available by making a separate production of the flotation froth. After considering the matter, however, it was found that there is no difference, since 1½% of copper is lost whether it is in the flotation concentrate or in the table concentrate. If the two are mixed, the assay is lower in copper, but the tonnage is greater, and this offsets the higher assay but lower tonnage of the flotation froth.

At the first suggestion to return the flotation tailings to the Dorr thickener, in which the flotation feed is thickened, it seems that there were several things that would defeat the purpose. In the first place it might be supposed that the pulp would build up until the thickener would not handle it properly. Or, if this did not happen, it might be that by crowding the thickener with more pulp, the additional pulp would crowd some of the valuable minerals over the overflow, and they would go to waste. The pulp does gradually build up in the thickener, but this is overcome by allowing the flotation tailings to run to waste through the tailrace one hour in every eight. The other

effect is a slight increase in the value of the thickener overflow, but a marked difference in the value of the overflow product and the normal discharge. The flotation tailing averages about 40c. in gold, and the same in silver.

The overflow from the thickener averages about 40c. gold and about 20c. silver. Thus 20c. additional saving per ton is gained by this procedure. Considering that the total value of the flotation feed is about $2, this means an additional saving of 10%. When the tailing from the flotation machine is added to the thickener, the feed to the flotation machine contains 6 parts of water to one of ore. When this tailing is discharged directly to waste, the consistency is 9 to 1. When the tailing is returned to the thickener, the value of the overflow is about 60c. in total gold and silver. When it is bypassed to waste the average value of total gold and silver is about 55c. The difference is due to the silver content. Thus, for seven hours out of the eight the tailing from the mill is two products, the first of which is coarse sand from the classifier, having an average value in total gold and silver of 55c., and the second of which is the overflow from the Dorr thickener, with total value in gold and silver of 60c. The remainder of the time the tailing is composed of three products, of which the first two are the same as those just mentioned, and the third is a discharge from the flotation machine, having a total value in gold and silver of 80c. per ton. Using these figures as a basis on a $2 feed, the flotation recovery is about 70% of its own feed. The additional saving made by this machine in connection with recovery made by tables, makes the mill total recovery about 87 to 90%. This is satisfactory considering the low content of the crude mill feed.

Of the flotation feed 85% will pass through a 200-mesh screen and about 90% of the flotation concentrate will pass through the same screen. The oil is added in a small box under which the diaphragm pump discharges just before the pulp enters the machine. Oil is added at the rate of 2½ pounds per ton of dry feed. The cost has been materially reduced by mixing three different kinds of oil.

In this case the oil mixture consists of one part of thick crude wood tar—fairly cheap—one part of spirits of turpentine—more expensive—and four parts of a cheap local mineral oil. This mineral oil constitutes a cheap base for carrying the other

oils. It is not always possible to find a mixer that will give the high recovery and at the same time make clean products. By mixing oils as is done at the Oneida Stag, the cost per gallon for oil on the ground is reduced from 45 to 23c. This reduces the cost of oil per ton of crude mill feed from 6 to 3c. It has been estimated that the total cost of treatment, including flotation, is $1.85. Of this flotation costs 35c. The accompanying table shows a list of average assays of products in various places as indicated.

VALUE OF VARIOUS FLOTATION PRODUCTS

Sample	Au, Oz.	Ag, Oz.	SiO_2, %	Cu, %
Flotation feed	0.07	2.00	.....	..
Flotation tailing	0.02	0.80	....	..
Flotation froth (total 8 cells)	0.60	15.00	24.00	3.5
Flotation, first cell	0.70	17.00	18.00	5.0
Flotation, eighth cell	0.50	13.00	30.00	2.0
Table concentrate	2.25	8.00	9.00	1.3
Dorr-thickener overflow	0.02	0.35	....	..
Sand from the Dorr classifier	0.02	0.30	....	..
Mixed concentrates from dewaterer	1.70	11.50	16.00	2.5

In comparing the former cyanide practice with the present flotation plant work, the advantages of the latter are striking. An effective comparison is made by considering the two flow sheets. In the flotation mill the discard included three Dorr thickeners, three Dorr agitators, an air compressor for the agitator, and a motor to drive it, two zinc boxes, a melting room, solution tanks, and the necessary pumps. The amount of machinery represents considerable outlay, and the saving is material.

The next comparison is in treatment cost. Cyanide costs 80c. per ton of mill feed, or $1.50 per ton of ore actually treated by cyanide. Flotation costs 35c. per ton of crude mill feed, or 66c. per ton of ore actually treated. The difference between the two, 45c. per ton, represents the total profit per ton of mill feed with the flotation machine. The difference in the cost of installation is another advantage in favor of flotation. The actual cost of changing the mill over to flotation from cyanide was only about $2,000. This includes the flotation machine and all labor required to install and connect it properly. Flotation has put this mill back into a state of productiveness and

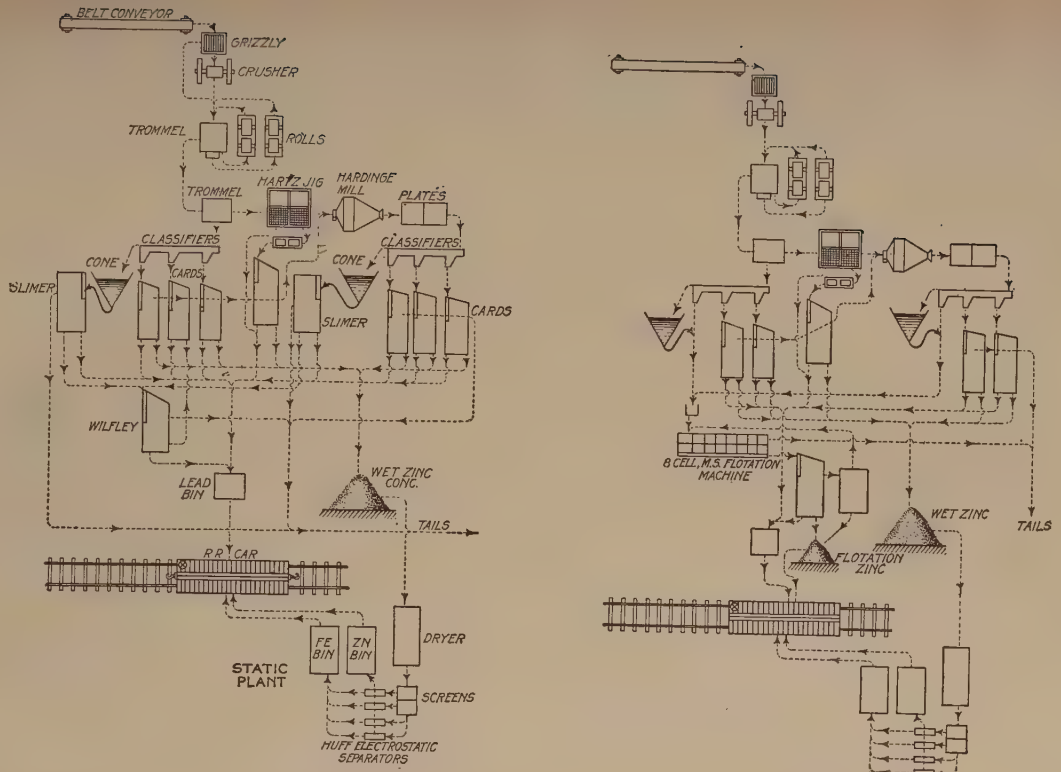


FIG. 36.—FLOW SHEET BEFORE AND AFTER THE CHANGE TO FLOTATION.

opened up for it a future better than might have been the case with any other process or combination of processes.

Floating Flour Gold.—Another flotation installation * was described by this same writer, and since it is of interest, some excerpts from the article will be given here. An interesting question arose in the treatment of the difficult ore, presenting a common but undesirable problem. In the early history of the mine the ore ran high in gold and silver. Later, mixed sulphides of zinc, lead, and iron became dominant. The first concentrating mill of modern design was erected about three years ago, and succeeded in saving, to a certain extent, the zinc, iron, and lead sulphides, but the gold and silver recovery was not satisfactory. This mill was treating ore of an average assay of 0.3 oz. gold, 2.5 silver, 5% lead, 8½% zinc, 3½% iron, and 0.5% copper. The gold was free and so fine that panning would not show a color. No hand specimens of gold were ever seen in the crusher feed, although occasionally a small piece was caught on the jig screens. Since the gold was fine, it was necessary to grind the ore to an extreme degree, to liberate for concentration. Cyaniding was impossible commercially.

After grinding to 8 mesh, as much sulphide as possible was removed on Card concentrators, and one Harz jig. Tailing was then reground to —30 mesh, amalgamated on plates and reconcentrated on concentrators. At various times the scheme was alternated by using carpets in place of plates, the free gold from the first riffle on the table being amalgamated in an arrastre. The simplified flow sheet indicates the source and disposal of slime. The high maintenance cost of slime concentrators, together with the great amount of space occupied and the low saving they made rendered this arrangement undesirable. The difficult problem, however, still remained. The zinc concentrate from the table was unfavorable, since it assayed 0.75 oz. gold, 5 oz. silver 10% lead, 33% zinc, 10% iron, 2.2% copper, and 11% insoluble. In order to raise the percentage of zinc the Huff electrostatic system was employed. A plant was erected that would treat all the zinc concentrates from the wet mill, and under these conditions the saving did not exceed 55% to 65% on any mineral. With such a loss it was natural to seek a process that would make a better saving.

* "Flotation of Flour Gold," *Eng. and Min. Journal*, July 1, 1916.

Flotation was suggested, and since a few preliminary tests gave promising indications a systematic campaign of testing was inaugurated.

Early tests were run on entire mill tailings, which showed that a small quantity of salable product could be made, but the tailing operated on was so lean than 90% recovery did not justify an expensive installation. The average feed for these tests was —30 mesh and assayed 0.12 oz. gold, 2.3 oz. silver, 2% lead, 0.3% copper, 1.5% iron, and 3.5% zinc. From this feed rough concentrate was recovered, and assayed 0.5 oz. gold, 2.8 silver, 3.1% copper, 10.1% lead, 12% iron, and these tests weighed heavily against an installation operating under such conditions. Acid would have necessitated a more costly plant, more floor space, more difficult operation, and additional boilers for generating steam, besides which the cost of acid alone would have been almost prohibitive.

Under these circumstances, the scheme of treating the entire tailing was abandoned, and testing was confined to the slime alone. A small amount of clean lead, and a slightly greater amount of zinc was made from the slime by gravity treatment. The latter was dirty and had to be reclaimed on another table, riffled especially to treat the slime. The accompanying table shows some results obtained from this arrangement.

RESULTS FROM TREATMENT OF SLIME ALONE.

	Au, Oz.	Ag, Oz.	Pb, %	Zn, %
Feed	0.14	2.3	4	6.3
Lead concentrates	3.00	8.8	38	15.0
Zinc concentrates (to be recleaned)	0.70	6.0	12	18.0
Zinc concentrates (cleaned)	0.35	7.0	8	36.0
Lead concentrates (from recleaning table)	2.00	9.0	40	10.0

Slime concentrators received a total of 30 tons of feed each day, of which 90 to 95% was passed through a 200-mesh screen. The first series of flotation tests on these slimes were made with acid and heat. All normal variations of testing were tried and a saving of 80% was common on all minerals. Calculations showed, however, that the cost of acid was a serious item. Certain tests disclosed the possibility of simplifying and cheapening the process, and in this change a new set of conditions were

introduced eliminating the acid, heat and any considerable pulp thickening. Products formed under these conditions assayed 0.65 oz. gold, 12 oz. silver, 18% lead, 35% zinc, low iron about 4% insoluble. On this product, however, further treatment had to be made to separate it into salable products. The high percentage of lead indicates that a fair separation might be expected. Furthermore, the froth was not hard to break up. A commercial unit was installed, and as soon as it was put into operation better results were obtained than in testing. Froth concentrate, as removed, was washed with clear water to a Wilfley table. The table classified the relatively coarse lead and zinc and made a perfect separation of them, but had very little effect on the remaining fine slime. The coarse lead and zinc products where heavy enough to settle were easily dried and handled. The difficulty was found with the fine products. The slime concentrate was pumped into a settling box, and the clear water overflow conducted back to the flotation machine. The products were dried only enough to allow them to be stacked. Steam at boiler pressure was used in a coil. The list of assays are given in the accompanying table.

RESULTS FROM FINAL TREATMENT SYSTEM

Sample	Tons per 24 Hr.	Au, Oz.	Ag, Oz.	Pb, %	Zn, %	Fe, %
Flotation feed	30-35	0.14	2.5	3.0	5.5	1.0
Flotation tailings	28-30	0.03	0.8	0.8	1.5	..
Flotation froth (total)	4-5	0.65	10.0	15.8	36.0	..
Flotation zinc (coarse), after table treatment	2-3	0.50	9.0	5.0	54.0	4.0
Flotation zinc (fine) after table treatment	1-2	0.50	12.0	11.0	40.0	5.8
Flotation lead, after table treatment	½-1	3.40	11.0	75.0	5.0	..

One of the first things noticed in the operation of the flotation machine was the fact that the free gold floated. The greatest gold values were in the first riffles of the Wilfley table, although the lead content extended over many more than did the high gold value. It was also shown positively that the lead did not contain any marked amount of gold. At times there was a small accumulation of gold in spots on the table that had become greasy, and then the flour gold could readily be seen.

The percentage of saving made reached about 85% gold of the gold.

The machine cost approximately $1,000, including material, labor, and designing. The peculiar advantages of flotation here are that no acid is used, no artificial heat, no additional pulp thickening devices are necessary. Froth is easily broken down after removal from the machine, no classification is necessary before concentrating on the table, and the saving of all valuable slime content is raised from 20 to 75 or 80%. The process is simple in operation, produces better products than were ever before possible at the mill, and no slime losses occur in dust. The static plant was relieved of undesirable slime, and there was no royalty to pay as with the static process. One man per shift only was required to operate the plant, which will run successfully on a lean slime feed. Not only are the actual mill results extremely favorable, but there are other considerations that tend to make the whole property more valuable. Among these may be mentioned the impounded tailing dump of approximately 50,000 tons carrying gold, silver, zinc and lead that can be retreated at some future date. Lower grade ore can be sent down from the mine, as the recovery of concentrate per ton of feed is higher with the flotation installation. Many tons of low-grade ore from the mine dump can now be profitably treated. And last, the possibility of radical changes in the milling system are open, which changes might result in lower treatment cost of better products and higher recovery. This might be accomplished by laying more stress on the flotation and giving less work to the static mill. Although this installation was more or less experimental, it actually paid for itself and the test in two weeks of operation. Inasmuch as the installation has demonstrated that flotation can be used commercially to recover gold, this plant has shed further light on modern milling practice that will be welcomed by the engineering fraternities.

CHAPTER XI

FLOTATION CONCENTRATION AT ANACONDA

At the plant of the Anaconda Copper Mining Co., near Butte, Mont., one of the most extensive flotation plants in this country has been put into operation. The practice has been adequately described by Frederick Laist and Albert E. Wiggin in the *Bulletin* of the American Institute of Mining Engineers, March, 1916, from which the review in this chapter has been abstracted.

FIG. 37.—THE ANACONDA PLANT, NEAR BUTTE, MONT.

The concentrator at Anaconda, as remodeled for flotation, consists of eight sections, each of 2,000 tons per day capacity, giving a grand total of 15,000 tons per day, allowing for shutdowns, repairs, etc. All sections are alike with the exception of Section 1. In this section, Hancock jigs are used in place of Evans jigs and tube-mills are used in place of Hardinge mills. The drawing shows the flow sheet of Sections 2 to 8.

Milling Division.—The ore is fed from the bins to a 2-in. round-hole shaking screen, the oversize going to a 12 by 24-in. Blake crusher. The product from this crusher is delivered to a 2-in. round-hole trommel, the oversize of which is sent to two 8 by 20-in. Blake crushers. The product from these crushers, together with the undersize from the 2-in. screens, is elevated and passed through 1-in. round-hole trommels. The oversize from

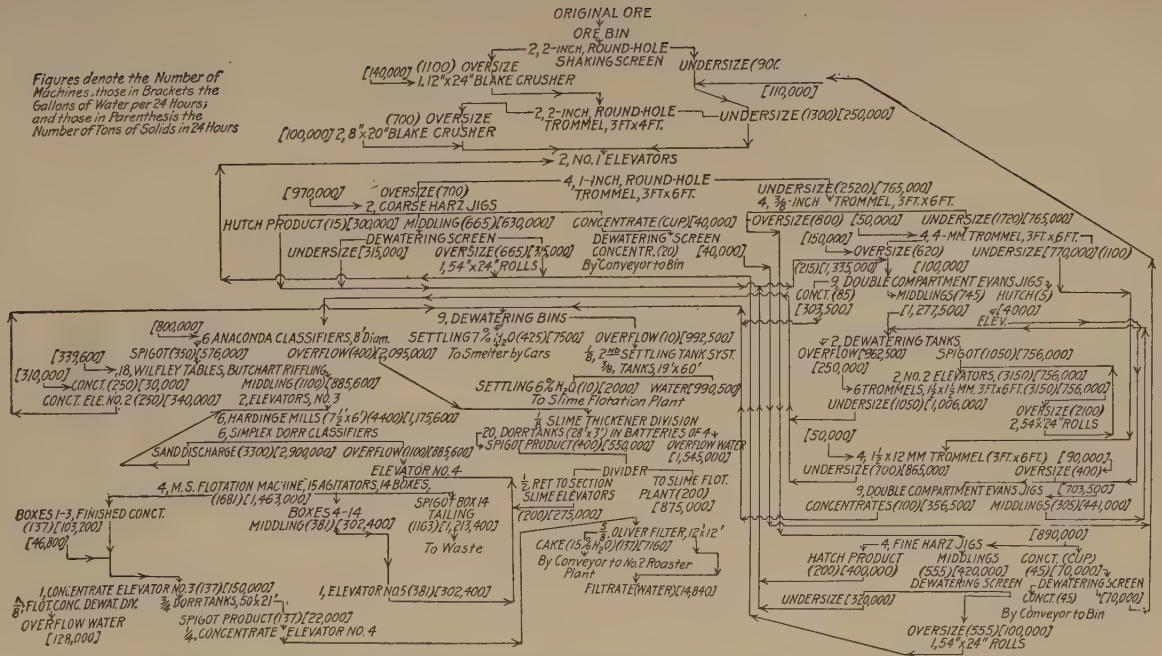


FIG. 38.—INSTALLATION OF FINE-GRINDING AND FLOTATION EQUIPMENT AT THE ANACONDA CONCENTRATOR. SECTIONS 2 TO 8.

this is treated in coarse Harz jigs, making a middling and a concentrate; the undersize is passed through ⅜-in. trommels, the oversize being treated in fine Harz jigs making a concentrate and a middling. All sections are alike up to this point. In Section 1, the undersize from the ⅜-in. trommel is screened on 1½ by 12-mm. trommels, the undersize going to the Anaconda classifiers and the oversize to the Hancock jigs. The treatment of the products from this point is the same in all sections, except that Section 1 uses tube-mills in place of Hardinge mills for grinding, as noted previously. The undersize from the ⅜-in. trommel is screened through 4-mm. trommels, the oversize from these going to the double compound Evans jigs and the undersize going to 1½ by 12-mm. trommels. The undersize from these trommels goes to the Anaconda classifiers, the oversize to double compound Evans jigs. The two sets of Evans jigs make a concentrate which goes to the dewatering bins and a middling which is ground for further treatment.

The concentrate from the coarse Harz jigs is dewatered and conveyed to bins. The middling is screened on a dewatering screen, the undersize together with the hutch product from the coarse Harz jigs going to the Evans jigs. The oversize is passed through rolls, 54 by 24 in., and thence back into the system ahead of the 1-in. round-hole trommels. The concentrate from the fine Harz jigs is sent to the bins. The middling is screened through a dewatering screen, the oversize going to 54 by 24-in. rolls and then back into the system ahead of the 1-in, round-hole trommels. The undersize of the dewatering screen together with the hutch discharge of the fine Harz jigs goes to the Evans jigs.

The concentrate from the Evans jigs is dewatered in bins to about 7% moisture, and sent to the smelter. The jig concentrate assays about 15% insoluble and 8% copper. The middling, together with the hutch product is dewatered in tanks and screened through 1½ by 12-mm. trommels, the undersize from which goes to the Anaconda classifiers, the oversize through 54 by 24-in. rolls, and back to the 1½ by 12-mm. trommels.

The spigot product from the Anaconda classifier is treated on 18 Wilfley tables, fitted with Butchart riffling, making a concentrate and a middling. These tables make a concentrate assaying 25% insoluble and a middling assaying 0.9% Cu. The con-

centrate is sent to the dewatering bins, together with the fine jig concentrate, and the middling is sent to the 10 by 4-ft. Hardinge mills. The overflow from the Anaconda classifiers is sent to the slime thickener division, consisting of 28 by 3-ft. Dorr tanks. The spigot product from these tanks is divided; about one-half is returned to the section and the remainder is sent to the slime plant.

The product from the Hardinge mills is treated in six simplex Dorr classifiers—one classifier to each mill—the overflow going to the flotation division and the classifier sand being returned to the mill.

At the time it was first decided to remodel the concentrator, it was not definitely known whether pebbles or steel balls would be used for grinding. To provide for this uncertainty a compromise was effected. The mills were made 10 by 4 ft. and built sufficiently strong for steel balls in case balls were used. Each mill was equipped with a 225-hp. motor directly connected through a flexible coupling. The mill filled with pebbles takes from 95 to 115 hp. to operate. In case steel balls were used it was planned to put in a false wood lining back of the steel lining in the cylindrical part of the mill to reduce the effective diameter of the mill.

This latter plan was finally adopted, and the Hardinge mills will be equipped with the false wood lining, 15 in. thick, in the cylindrical part of the mill, and a Cascade steel lining. With this form of lining, the mill is virtually 7½ by 6 ft. and requires about 225 hp. when loaded with steel balls.

Flotation Division.—The flotation division consists of four Minerals Separation machines each having 15 agitators 3 ft. square, and 14 spitzkasten or floating compartments. The agitators for the Minerals Separation machines are of gun metal and are driven by bevel gears from a line shaft, the direction of rotation of the agitators alternating. The machines are made of California red wood; the agitator boxes are further lined with hard maple extending about 18 in. from the bottom of the box. Each machine has an individual drive, power being supplied to the line shaft by a 150-hp. motor running at 385 r.p.m. The speed of the agitators is 225 r.p.m. and as the impellers are 18 in. in diameter, the peripheral speed is about 1,060 ft. per minute.

Each machine makes three products, a concentrate that goes to the dewatering division, a middling that is returned to the head of the machine, and a tailing that goes to waste. The concentrate is taken from the first three to five spitzkastens and the middling from the last nine to eleven. A portion of the pulp is overflowed from the last three spitzkastens together with the froth. About 6 to 8 lb. of (50° Bé.) H_2SO_4 per ton of

FIG. 39.—PART OF THE MINERALS SEPARATION INSTALLATION AT ANACONDA.

flotation feed is used together with 2 to 3 lb. of kerosene sludge acid and ½ to 1 lb. of crude wood creosote. A portion of the wood creosote is added ahead of the Hardinge mill (about 0.03 to 0.05 lb. per ton of feed) and the remainder is added in the sixth agitating compartment. The sulphuric acid and sludge acid are added at the head of the machine. The pulp is heated to from 60° to 70° F., by passing live steam into it at the head of the machine. Three machines are used for treating sand and the fourth for treating current slime from the upper portion of the mill. Each machine has a capacity of about 400 tons per day on sand and 175 tons on slime.

The method of adding the oil and acid is rather unique. The mechanism consists of a revolving disk to which are attached, around the circumference, a number of cups. This disk

is set vertically so that its lower edge dips into a pan of acid or oil. As the cups come around they are filled and later discharge their contents into a suitable launder leading to the flotation machine. The disk is driven by the friction of a wheel against another disk attached to the main drive. The wheel is run at constant speed and by varying the point of contact between wheel and disk any speed desired can be given to the main disk and thus the amount of oil or acid added can be regulated. In addition to the speed regulation, the amount of oil or acid fed may be varied by adding or removing cups or by changing the size of the cups.

In December, 1915, seven sections were operating on the new flow sheet, and the whole mill is now remodeled. The sections were being remodeled one at a time. All the work was done by the company's engineering force. Things had been so well organized and systematized that it required less than 30 days to tear out the old section and install the new equipment, ready for operation.

The following table gives metallurgical data concerning the operation of the mill. Line 1 gives the monthly assay of second-class ore for October, which is the feed to the mill. Line 2 gives the monthly assay of the flotation tailing from the remodeled sections for October. The feed to the flotation machines during the month consisted of reground sand tailing and a portion of the thickened mill slime which was returned to the mill and treated in the fourth machine in each remodeled section. The tailing assay shown below, 0.13% Cu, is for the total sand and slime tailing produced. The sand tailing alone averaged 0.10% Cu and the slime tailing averaged about 0.25% Cu.

METALLURGICAL DATA ON MILL OPERATION

	Per Cent. Cu	Per Cent. SiO_2	Per Cent. Al_2O_3	Per Cent. Fe	Per Cent. S	Per Cent. CaO	Ounces per Ton	
							Ag	Au
Feed to concentrator.....	2.85	59.1	9.4	10.6	11.8	0.6	2.00	0.0070
Total concentrator tailing (flotation)	0.13	81.6	11.3	1.0	0.5	0.5	0.10	0.0005

Following is an estimate of the power consumption per 2,000-ton section, including its proportion of slime treatment.

POWER CONSUMPTION PER SECTION

	Horsepower
Feeding and coarse crushing	125
Roll crushing	220
Jigging	60
Screening	37
Conveying and elevating	237
Table concentration	25
Fine grinding	655
Flotation of sand and slime in mill	426
Dewatering mill slime pulp	3
Flotation of slime in slime division	109
Dewatering flotation concentrate	25
Sampling and assaying	1
Total	1,923
Horsepower per ton of ore	0.96

The Slime Flotation Plant.—Because of lack of space in the mill an auxiliary plant had to be installed to handle the extra slime. This plant consists of 20 Minerals Separation machines of the same type and size as those used in the concentrator, and five 50 by 12-ft. Dorr tanks for dewatering the concentrate (Figs. 6, 7, and 8). The plant is designed to treat about 2,000 tons of current slime and 1,000 tons of pond slime. This plant was in operation on December 15, 1915. What this plant may be expected to do, so far as the treatment of current slime is concerned, may be judged from the results obtained in the experimental slime machine, which has been operating regularly for more than a year.

The accompanying table gives the analysis of the current slime and the assay of the composite tailing sample for the month of June. These are typical of the results which may be expected in the large plant.

OPERATION OF EXPERIMENTAL SLIME-FLOTATION PLANT

Per cent.	Feed (Current Slime)	Tailing	Concentrate
Cu	2.10	0.27	12.0
SiO_2	61.00	67.70	20.0
FeO	4.10	2.70	28.0
S	4.40	1.10	
Al_2O_3	19.00	18.30	
CaO	0.60	0.70	
Ag[1]	1.80	0.20	
Au[1]	0.005	0.001	

[1] Ounces per ton.

The treatment of the pond slime offers a few more difficulties than that of the current slime. This slime has been exposed to the weather for a number of years so that the copper is partially oxidized, consequently that portion probably cannot be

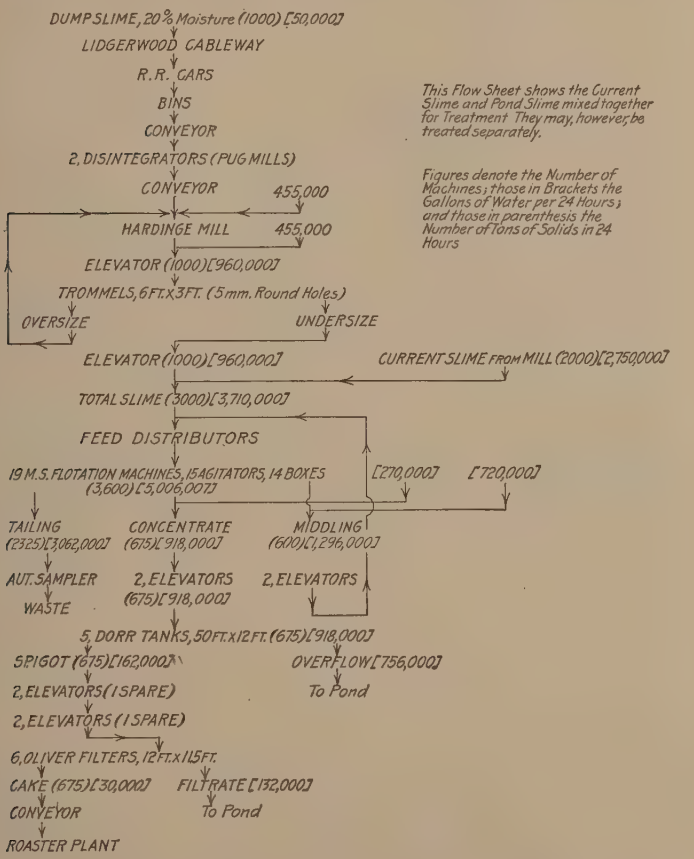

DUMP SLIME, 20% Moisture (1000) [50,000]
LIDGERWOOD CABLEWAY
R.R. CARS
BINS
CONVEYOR
2, DISINTEGRATORS (PUG MILLS)
CONVEYOR 455,000
HARDINGE MILL 455,000
ELEVATOR (1000) [960,000]
TROMMELS, 6 FT. X 3 FT. (5 mm. Round Holes)
OVERSIZE
UNDERSIZE
ELEVATOR (1000) [960,000]
CURRENT SLIME FROM MILL (2000) [2,750,000]
TOTAL SLIME (3000) [3,710,000]
FEED DISTRIBUTORS
19 M.S. FLOTATION MACHINES, 15 AGITATORS, 14 BOXES (3,600) [5,006,000]
[270,000]
[720,000]
TAILING (2325) [3,062,000]
CONCENTRATE (675) [918,000]
MIDDLING (600) [1,296,000]
AUT. SAMPLER
WASTE
2, ELEVATORS (675) [918,000]
2, ELEVATORS
5, DORR TANKS, 50 FT. X 12 FT. (675) [918,000]
5 PIGOT (675) [162,000]
OVERFLOW [756,000]
To Pond
2, ELEVATORS (1 SPARE)
2, ELEVATORS (1 SPARE)
6, OLIVER FILTERS, 12 FT. X 115 FT.
CAKE (675) [30,000]
FILTRATE [132,000]
CONVEYOR
To Pond
ROASTER PLANT
This Flow Sheet shows the Current Slime and Pond Slime mixed together for Treatment They may, however, be treated separately.
Figures denote the Number of Machines; those in Brackets the Gallons of Water per 24 Hours; and those in parenthesis the Number of Tons of Solids in 24 Hours

FIG. 40.—ANACONDA SLIME-FLOTATION PLANT AT ANACONDA, MONT.

floated. Some results from the flotation plant at Great Falls, covering a week's operation, are tabulated below. This character of material has been treated for some time at the Great

Falls plant, and the results should be a good criterion of what may be expected here in the treatment of dump slime.

Operation of Slime-Flotation Plant at Great Falls

	Per Cent
Recovery based on concentrate	78.90
Recovery based on tailing	80.90
Average total Cu in tailing	0.53
Average soluble Cu in tailing	0.13
Average sulphide Cu in tailing	0.40
Average total Cu in feed	2.52

At Great Falls, one double Minerals Separation machine of the same design and size as used at Anaconda is treating from 300 to 350 tons of dump slime daily.

Sulphidization Experiments at Great Falls.—Experiments covering a period of five days, in which five tons of sodium sulphide were consumed, were made at the Great Falls plant, to determine the feasibility of sulphidizing the oxidized copper prior to flotation. Sodium sulphide, in solution, was added at the pug mill together with the dump slime. No difficulty was found in sulphidizing practically all of the copper which went into solution, but it was found that all oxidized copper was not dissolved during its passage through the pug mill and flotation machine.

Moreover, on the addition of sodium sulphide, the froth immediately broke up—a large part of the natural sulphides no longer floating, and the tailing assay showing a marked increase, although the precipitated sulphides floated. Hardly any froth was formed, probably because of the colloidal state of the precipitated sulphides rather than the result of any deleterious action on the oils used of the sodium sulphide, or the sodium sulphate formed.

The cause of the breaking of the froth was not clear. It may have been due to the sodium sulphate formed, or, what seems more probable, to some impurities in the sodium sulphide, the latter being only about 50 per cent. pure. This effect was very general, the froth on the second machine breaking up, although no sodium sulphide was added to it, except through a return middling elevator which was common to both machines.

The Flotation-Concentrate Dewatering Plant.—The de-

watering of the flotation concentrate is done in six 50 by 12-ft. Dorr thickeners. Five tanks of the same size have been provided for the slime plant. The pulp is delivered to a baffle box about 5 ft. square in the center of the tank, and extending down to within a few inches of the rake arms. Surrounding this is another baffle about 15 ft. square and extending about 18 in. below the surface of the water. These baffles catch a

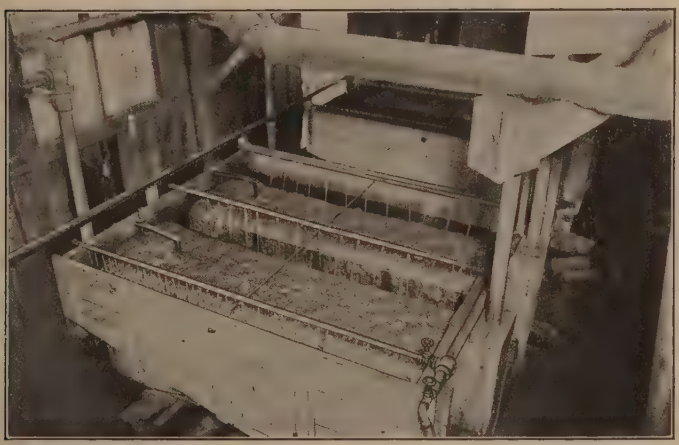


FIG. 41.—A CALLOW FLOTATION UNIT IN OPERATION AT ANACONDA.

large portion of the froth which is there broken up by means of a water spray. The capacity of these tanks when treating flotation concentrate is from 200,000 to 250,000 gal. of pulp per 24 hr., although they will probably not be required to handle more than 200,000 gal. Operating even at this capacity, there is a small amount of finely divided material that will not settle. Therefore, the overflow from these tanks is run to a slime pond and the solids collected for future treatment. The capacity of these same tanks when treating round-table concentrate is about 1,000,000 gal. of pulp per 24 hr.

Some experiments were made to increase the capacity of the tanks by the use of glue. Indications from tests in a beaker seemed to indicate that glue would greatly aid the settling, but this did not prove to be the case. The glue caused the colloidal

material to coagulate, but it did not actually increase the capacity of the settling tanks to any great extent.

The density of the pulp delivered to the tanks averages from 18 to 20% solids, and the spigot averages about 60% solids. The spigot product is further dewatered in Oliver filters 11½ ft. diameter by 12 ft. face. There will be eleven of these, each capable of handling 150 tons per 24 hr. and making a cake containing about 15% moisture. The cake from the filters is delivered to a belt conveyor and is carried with the fine mill concentrate to the new roaster plant. In this way a fairly good mixing of the concentrates will be obtained.

CHAPTER XII

FLOTATION IN PRACTICE

To ores of zinc and lead flotation has appeared to be particularly adapted and, as a matter of fact, even its inventors thought for a long time that its usefulness would be limited to special classes of ores. It was much later that it was proved applicable to copper and other ores. The wide application in Australia was probably due to the existence of so many complex ores in the metallurgy of which some aid was sought. In the United States, too, the first important application was on a zinc-bearing ore—that of the Butte and Superior mine, at Butte, Mont. It has been widely applied, since that time, to other similar ores as well as those of different character.

The Gold Hunter Mill.—The Gold Hunter mill, owned by the Gold Hunter Mining and Smelting Co., is situated in Hunter Gulch, about a mile northeast of Mullan, one of the mining communities of the Coeur d'Alene District. It has a mining capacity of 20,000 tons per year and makes use of concentration by the application of jigs, tables, and oil flotation. The accompanying flow sheet shows in general the operation of the mill. An important use for flotation has been found in treating the Hunter ores profitably, and it may be said that not until flotation became a permanent part of mill treatment was continuously profitable operation possible.

The mill at the present time treats about 310 tons of ore per 24 hr. From this about 35 tons of concentrate is produced, about half of which comes from the flotation department. While under the former system of table and vanner concentration, only about 50 to 60% of the valuable minerals could be recovered, with the addition of the flotation units the total extraction has risen to 80%, thus making it entirely clear what a great difference has been made by the introduction of flotation in this district.

Ore from the mine-ore bin is passed over a conveyor belt

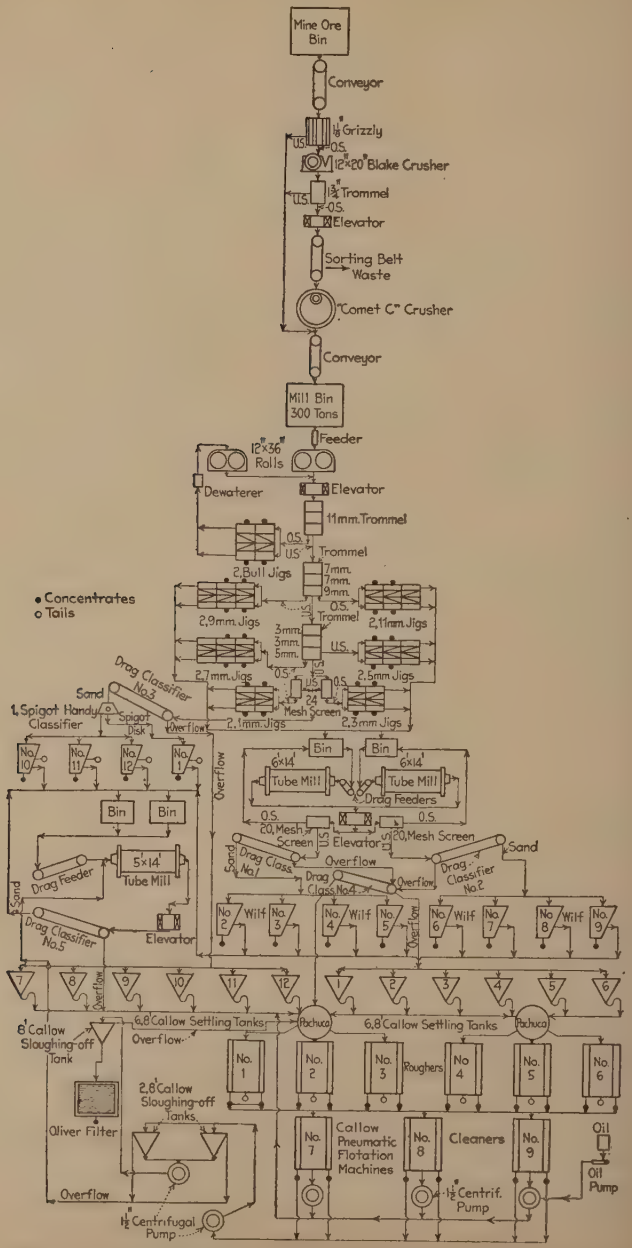


FIG. 42.—FLOW SHEET OF THE GOLD HUNTER MILL, AT MULLAN, IDA.

to a grizzly having 1⅛-in. openings, the oversize of which is put through a 12 x 20-in. Blake crusher. From the crusher the material goes to a trommel with 1¾-in. holes, the oversize being elevated to a sorting belt, where a portion of the waste is removed by hand. The balance of the oversize goes to a Comet crusher, the discharge of which meets the undersize from the trommel and grizzly and is carried on a belt conveyor to a mill bin having a capacity of 300 tons.

From the mill bin the ore is passed through a set of 12 x 36-in. rolls, the discharge from which is elevated to a trommel having 11-mm. openings. The oversize goes to two bull jigs, the tailings of which are dewatered and crushed in another set of 12 x 36-in rollers, the discharge going back to the elevator which precedes the 11-mm. trommel. From the trommel the undersize is passed to a set of screens and jigs, the flow being clearly shown on the accompanying flow-sheet drawing. The sand is dewatered in a drag classifier and concentrated on four Wilfley tables, the concentrates from which are collected in a bin. The table tailing is then reground in a 5 x 14-ft. tube mill, elevated, dewatered, and reconcentrated. The flow from the jigs is reground, classified, and concentrated on Card tables, as is shown in the flow sheets. At this point preparation is made for treating the tailing from the concentrators by flotation. The pulp is thickened in Callow settling tanks and then delivered into two small Pachuca tanks, where mixture with the frothing oil is accomplished. Creosote oil in the proportion of about 1/3 lb. per ton of ore is mixed in the tanks and then delivered to six Callow roughing flotation machines. Three of these are supplied by each of the Pachuca tanks. From the roughing machines the concentrate is sent to three Callow cleaners, these being machines of the same type as the roughers. Each of them is supplied by two of the rougher machines. The concentrate, finally cleaned, is pumped into two 8-ft. Callow sloughing-off tanks and then to a third Callow cone, whence it is delivered to an Oliver filter. The filter delivers concentrates containing only about 8% of moisture. All solutions from the flotation department are returned to the Pachuca tank for further use, the object being to avoid the loss of any oil that may remain in them.

Among the important points brought out in practice of flo-

tation at the Gold Hunter mill is the necessity of giving much care and watchfulness to the small details of operation. The flow of pulp to the roughing and cleaning machines must be accurate in quantity, and what is even more important, the dilution must be constant. At this mill the pulp is comparatively thick—that is, contains a high percentage of solids—but as a general rule of flotation this does not apply, since different relations may be necessary for successful working of different kinds of ores. It is important that the proper working conditions, having been determined, shall be maintained absolutely to get best results. At the Hunter mill it takes 5.6 mechanical horsepower to provide compressed air for one Callow cell. It is considered that there would be some advantage in concentrating the flotation tailing on tables and steps may probably be taken to bring about this change.

Silver King and Daly-Judge Mills.—The recent general tendency to remodel concentrating plants so as to include "oil flotation" in the process is aptly illustrated at Park City, where at the old plants of both the Silver King Coalition and Daly-Judge * properties, flotation equipment has been installed during the past year. In neither case has the process proved a disappointment and in both improvement has been made over results obtained by the older methods. Not the least interesting feature is the decided difference in the method of applying the process in the two plants.

The presence of a considerable quantity of zinc in the Daly-Judge ore, and the consequent necessity for producing a zinc, as well as a lead-iron concentrate, is largely responsible for this difference. At the Silver King, where the zinc is negligible, the entire bulk of sulphide jig tailings is reground to pass 30 mesh and given a straight flotation treatment, the only recourse to gravity concentration being an occasional separation of the middling concentrate. Even this is necessary only when the ore happens to be unusually high in iron. The old concentrating tables have been entirely supplanted by flotation, and reduced operating and maintenance costs, somewhat better grade of concentrate and increased extraction have been the result.

At the Daly-Judge, on the other hand, only the slime un-

* "Flotation at Silver King and Daly-Judge," A. B Parsons, *Salt Lake Min. Rev.*, Feb. 29, 1916.

avoidably made in the usual crushing operations is treated by flotation. The lead and zinc are floated together and then both froth and tailing from the cells are tabled to effect a separation of the two concentrates. None of the tables have been dispensed with, so that operating and maintenance costs are consequently increased; the advantage derived is an appreciable increase in extraction and a slightly improved grade of zinc concentrate.

Silver King Coalition Operations.—The mine ore is, as heretofore, separated into two portions for milling purposes. The oxidized ore is still treated with jigs, followed by gravity concentrators, flotation being applied only to the tailing from the jigs in the "sulphide" section of the mill. The tailing has been crushed in rolls to pass a ½-in. trommel aperture and contains on an average of 4 oz. of silver and 1.5% lead. It is fed to two No. 64½ Marcy ball mills, 6 ft. in diameter and 4½ ft. long, with single-scoop feed. These mills operate with herringbone gear and are directly connected through a flexible coupling to 100-hp. motors, although they consume only about 60 hp. each, operating as at present. The liners are Krupp type, of chrome steel, and each mill is charged with 6,500 lb. of 4-in. chrome-steel balls. This is not the full charge, but is sufficient to handle the present feed. The two mills have ground the ½-in. tailing to pass 30 mesh at the rate of 600 tons per 24 hr., but are not now at full capacity.

The mills are followed by a revolving trommel equipped with 10-mesh screens, followed by a set of four duplex Callow screens which return the plus 30 mesh to the mills along with the oversize from the trommel. The result is a closed circuit with the undersize from the 30-mesh Callow screens supplying the feed for flotation. The screen analysis of the feed can be governed by regulation of the moisture in the Marcy-mill feed, best results in the cells being obtained when the mill feed is approximately 50% solid. This gives a minimum of very fine slime. The varying character of the ore from day to day makes it necessary to alter conditions frequently, and with different mixtures different sizing has been found preferable. It is the intention to replace the 30-mesh Callow screens with 48-mesh, with a view to meeting more nearly the requirements of all grades of ore, although much of it can be floated satisfactorily

with a 30-mesh maximum. A dilution of four to one for the flotation feed is approximated as nearly as possible.

Flotation Equipment.—The actual flotation equipment comprises three units, each including one 3-ft. by 14-ft. Pachuca mixer, two two-compartment primary-flotation cells, two secondary cells, and one "cleaner." The cells are all of standard Callow pneumatic design. Air for the fifteen cells is supplied

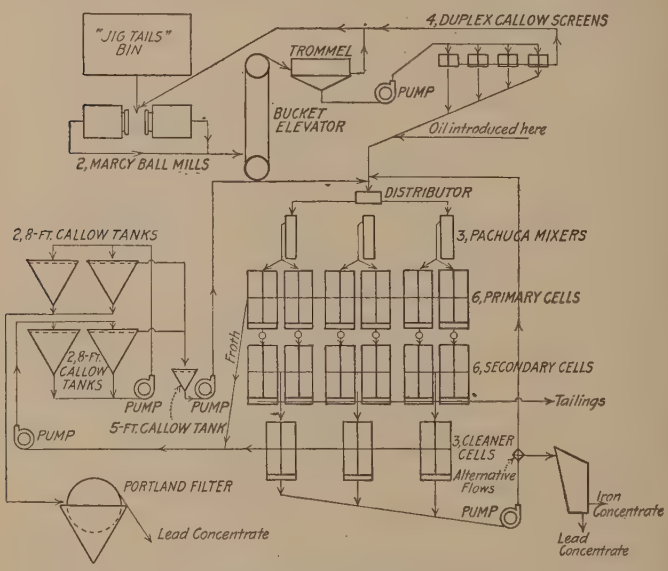


FIG. 43.—FLOW SHEET OF THE SILVER KING COALITION MILL, PARK CITY, UTAH.

at 5-lb. pressure by a Connersville blower handling 8½ cu. ft. of free air per revolution. The blower operates at 210 r.p.m. and is driven by an individual 75-hp. motor.

As originally installed it was planned to use the first four cells in each unit as roughers, in series by pairs; the tailing from the second pair was to be discarded, and the froth from all four was to be cleaned in the fifth cell. The tailing or middling from the final cell was to be returned to the head of the circuit and the froth filtered as the finished product.

However, it was found that a sufficiently high-grade concentrate could easily be floated in the first pair of cells and that it did not pay to put the additional burden on the cleaners. The present scheme, as detailed on the accompanying flow sheet, was accordingly adopted. The transfer from the primary to the secondary cells, which are at the same elevation, is effected by six air lifts constructed of 4-in. pipe. Each unit has a capacity of 200 tons per 24 hr., equal to that of the Marcy mills, but as previously mentioned the plant is not being operated at capacity at the present time.

An alternative step in the treatment of the middlings from the cleaner cells is to separate an iron and a lead concentrate on a No. 5 Wilfley table. At times the iron content of the ore is exceptionally high and a representative assay of the middling shows 2½% lead, 8% iron, and 6 oz. of silver. Treated on the Wilfley, this gives a high-grade lead concentrate and a marketable iron product running fairly high in silver. This procedure also eliminates to an extent the accumulation of iron that might result from the continual throwing back of the middling into the circuit.

The question of the most efficient and satisfactory oil has been thoroughly investigated and test runs show the best results with a mixture of 20% No. 80. Pensacola crude pine oil and 80% Denver creosote. A satisfactory substitute is an already-prepared mixture of No. 1,580 pine oil combined with crude wood creosote. One-fourth pound per ton of ore is allowed to drip through a small pet-cock into the undersize stream from the Callow screens. The resultant froth tends toward brittleness rather than toughness, is rather easily killed, and presents no great difficulty in handling.

Tailing from the secondary cells assays, approximately, 0.5% lead and 1.4 oz. silver, which is an improvement of more than 100% over results obtained in former practice.

It is practically certain that the Pachuca agitators or mixers can be eliminated without any bad effect on flotation. The oil will then, of course, be fed just ahead of the Marcy mills and the action in the mills, as well as in subsequent elevating and screening, would, in all probability, give sufficient mixing of the oil and pulp. This change is to be tried at once.

Handling the Concentrate Froth.—The froth concentrate is run through two pairs of 8-in. Callow cones, in series, preparatory to dewatering in a Portland revolving filter. Two rather novel schemes have been improvised to prevent overflow of the froth in these cones. A sheet-iron ring 10 in. high is put around the inner side of the overflow launder, just inside the rubber belt. This ring is perforated with several rows of 1/16-in. holes around the lower edge, which permit the water to overflow but hold back the froth. A large funnel is connected through a flexible 1½-in. hose connection, to discharge through a pipe running through the side of the tank at a point just about 3 ft. above the apex. The large end of the funnel is adjustable at a desired height above the water line and provides an overflow for any excess foam which would otherwise run over the ring already mentioned. Foam going through the funnel joins the spigot discharge from the cone. The overflow from the four tanks which is not entirely clear goes to a 5-ft. Callow tank, the thickened material from which returns to the flotation circuit. The final dewatering is done in an 8 x 8-ft. Portland filter, which gives a rather thin cake carrying as little as 9% moisture. Twenty pounds vacuum is obtained in a small rotary pump of the Connersville type. The filter can handle 75 tons in 24 hr., and with a moderately thick cake it is probable that the resultant product would be as low or lower in moisture.

It is an interesting fact that the filter here seems to handle the heavy galena concentrate with little or no trouble, while at the Daly-Judge an apparently similar concentrate, as will be mentioned later, has so far proved too much for a machine of the same manufacture. The dewatered product is dried over steam coils and shipped.

The advantages of flotation over the former table methods are several, and very clear at the Silver King. The first cost of installation has not been excessive; the operating cost for both labor and power has been decreased; percentage recovery has been increased and the grade of concentrate has been improved upon.

In this connection it is peculiarly interesting to note that, of two concentrates carrying exactly the same percentage of lead, one from gravity concentration and the other from flotation, the latter will assay higher in silver. This has been

demonstrated repeatedly, the variation amounting to as much as 10 to 15% of the total silver content. This would seem to indicate a decided tendency toward a selective preference in flotation for silver, and silver-bearing minerals.

The Daly-Judge Plant.—At the Daly-Judge plant, as has been pointed out, the entire situation is somewhat different. Flotation complicates rather than simplifies operations, costs for supplies, labor, and power are increased, and this increase must be more than offset by improved results. The equipment installed for flotation work includes, besides six standard Callow cells, a Dorr thickener, a Pachuca mixer, a small plunger pump for feeding oil, a Portland filter with small compressor and vacuum pump, a Connersville blower and various centrifugal pumps for transferring pulp. In addition there are five Callow tanks and seven Wilfley tables, part of the old equipment, in what may be called the flotation department of the mill.

The thickener is 30 ft. in diameter and 15 ft. deep, constructed with three decks. It takes the slime overflow from a jig and three Richards-Janney classifiers and delivers a slime containing approximately 15% solids, about 90% of which will pass 80 mesh. A thicker product could doubtless be obtained, as only about 35 tons are at the present time being handled in two 8-hr. shifts daily. However, this dilution meets the requirements for floating to best advantage. The pulp is elevated to the head of the flotation department in two stages by centrifugal pumps. The first pump discharges into a mixing box where the oil is added.

The rate of oil feed is regulated by a small plunger pump the speed of which can be altered by means of variable-speed pulleys. Further regulation can be had by manipulating a simple lock nut that varies the length of stroke of this pump. The purpose of introducing the oil here is to take advantage of the mixing action of the second centrifugal pump. Even more mixing would probably be beneficial, and if practicable it would no doubt be advantageous to feed the oil at the intake of the first stage pump.

Operations are still being carried out to determine the best oil. Efforts to find an oil which would make possible a preferential flotation of either lead or zinc to the exclusion of the other

were fruitless. Various mixtures showed a preference for one sulphide or the other, but it was impossible to get a good extraction of either one without also floating a prohibitive proportion of the other. The only course left was to float as much of both as possible in one operation and rely on concentrators for their separation. Amounts of various oils ranging from 1 to 4 lb. per ton of ore have been tried without a final decision being reached as to the most efficient.

Complicated Variation of Ore Supply.—The problem is somewhat complicated because of the variation in the ore supplied to the mill. Probably the best results, considered from every angle, have been obtained with the Pensacola company's No. 400 flotation oil. This is one of the final residual products of wood distillation, is comparatively cheap, and contains sufficient creosote and oil to give excellent flotation, especially good work being done on the zinc.

A single 4 x 20-ft. Pachuca tank effects further mixing before the pulp passes to the four roughing cells. The froth is cleaned in No. 1 cleaner, the tails from which are sent to the dump, although it seems unusual that they would not contain sufficient sulphides to warrant further treatment.

The two products, tailings from the roughers and froth from the cleaners, are sent separately to Callow tanks, and are then tabled on Wilfley concentrators. The tailings are thickened in the Callow tanks, but the froth is simply settled, there being no overflow. Considerable difficulty is experienced in breaking up the froth and this is one of the factors that must be taken into consideration in determining the best kind and amount of oil. Too persistent or voluminous a froth must be avoided. A patent nozzle known as the Koerting spray has been found useful in killing the froth. It is not only comparatively economical in the amount of water required, but at the same time more effective than any other sort of nozzle. The disposal of the various products from the different tables is shown in diagram on the accompanying flow sheet.

A closed circuit is formed in the treatment of the froth concentrate by reverting the "back-water" from the three tables to the head of the flotation circuit. The original flow sheet provided for the return of this product to No. 2 cleaner, from which a concentrate was to be sent direct through the last Callow

tank to the filter, and a tailing discharged as waste. This practice threw considerable zinc into the lead concentrate and, while the total metal recovery was somewhat higher, the net result was not so good, especially in view of the high price of zinc.

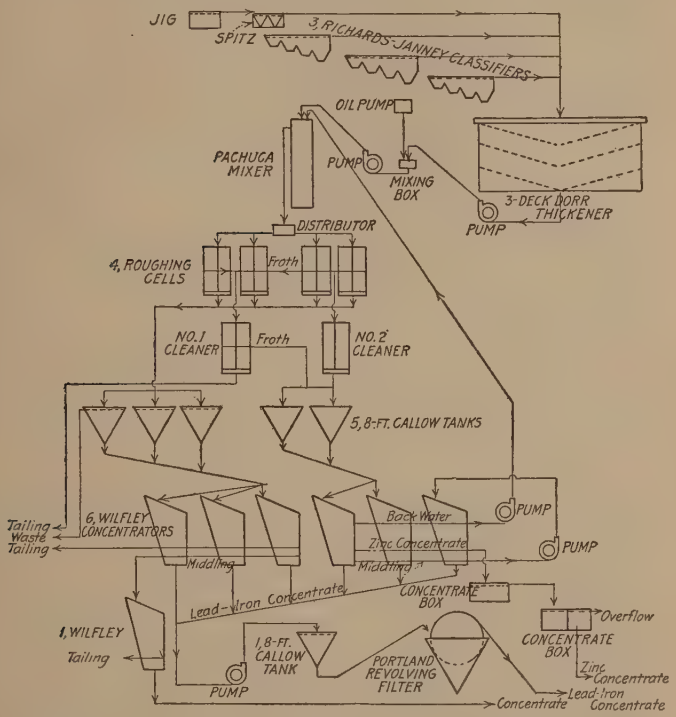


FIG. 44.—FLOW SHEET OF THE DALY-JUDGE MILL, PARK CITY, UTAH.

Following are representative analyses of the two grades of concentrate obtained, as well as of the feed to the roughing cells.

	Silica. P.C.	Zinc. P.C.	Lead. P.C.	Iron. P.C.	Silver. Oz.
Zinc concentrate	3.5	48.0	6.0	4.0	25.0
Lead-iron concentrate	1.5	7.0	42.0	16.0	35.0
Flotation heads	..	6.0	3.5	..	5.0

Handling the Concentrate.—The zinc concentrate is collected directly in two settlers, while the lead-iron concentrate is thickened in a Callow tank preliminary to intended dewatering by means of a 3-ft. by 8-ft. revolving-drum filter. The filter thus far has been unable to handle this material to any advantage although the manufacturer still hopes to be able to get results. Obviously the concentrate is extremely heavy, being largely galena, with some pyrite and some zinc. Whether this is the reason for the apparent failure of the filter, or whether there is some fault with the individual machine or installation is not known, but no method has yet been found to keep the concentrate in suspension and prevent its accumulation under and around the drum in a form almost like cement.

There is one feature in which it differs from the Silver King concentrate that may have considerable bearing in the case. At the Daly-Judge the treatment subsequent to flotation would have a tendency to wash off most of the oil coating from the ore particles; while at the former plant, where the froth is directly thickened and filtered, the remaining oil would exert a considerable buoyant force on the solid particles in the filter box. This would doubtless help hold them in suspension until picked up on the drum, and minimize the settling and packing which causes the trouble at the other mill.

Utah Leasing Co.'s Plant.—The new 500-ton plant of the Utah Leasing Co.* at Newhouse, Utah, has been built to work over approximately one million tons of tailing from the old Cactus mine. The plant is what might be called strictly a flotation unit, as the entire working up of the tailings is centered in a Minerals Separation flotation machine of newest design. In this respect it differs from most plants in which flotation is used to help in concentration, as at this plant flotation is the sole means of concentrating the ore.

The tailing is brought to the feeding hopper by means of a drag line and from this hopper is elevated to the bins, the elevator being of the continuous bucket type. A conveyor distributes over the ore bins, which have a capacity of about 550 tons. The ore is fed to two 8-ft. by 48-in. Hardinge pebble mills with extra large scoops by means of two Allis-Chalmers

* *Salt Lake Min. Review*, Nov. 15, 1915.

Challenge feeders. The Hardinge mills are connected in closed circuit with two Dorr Simplex classifiers, the minus 65-mesh material being sent to an elevator for delivery to the Minerals Separation machine and the oversize being returned to the Hardinge mills for regrinding.

The Minerals Separation Machine.—The Minerals Separation machine is of the type known as "6—6 combination," being 12 cells arranged in series, 6 cells of which are of the single-spitzkasten, 24-in. standard type, and 6 cells being of the double-spitzkasten, subaeration type, known as the Hebbard flotation cell. Eight hundred cubic feet of air per minute at 5-lb. pressure is added to the agitation in the Hebbard cells, the air being supplied by a Roots blower. The entire Minerals Separation machine is driven from a single line shaft, the speed of the impellers being from 425 to 450 r.p.m. The main body of the machine is entirely built of California redwood. The launders on both the standard and on the subaeration section are of the double type.

Method of Concentration.—A concentrate is made on the first three standard cells, to the first of which the feed from the classifiers is also added. The subaeration cells are used to make a middling, which is again returned to the head of the machine for recleaning. The concentrates are sent to large bins, with capacity of 200 tons, for settling, and the overflow is pumped back to the Hardinge mills. All launders have been made 14 in. wide and 11 in. deep, the extra size being to take care of excessive amount of froth.

Electric power is used exclusively, the power being received from the Beaver River Power Co., at 44,000 volts, which is stepped down to 2,200 and 440 volts respectively in the mill. The Hardinge mills are driven by a 150-hp. motor, connected to a single line shaft, driving both mills. The Minerals Separation machine is driven by a 75-hp. motor. The drag-line drums are driven by a 35-hp. motor.

The mill is fully equipped with efficient fire protection. Water is secured from the main South Utah pipe line, which has a capacity of 1,200 gal. per min., the source being at Wahwah Springs, approximately eight miles away. The mill is connected with a storage reservoir, the capacity of which is approximately 90,000 gals.

The Tailing Treated.—The ore in the tailing is almost exclusively a chalcopyrite and is comparatively little tarnished. The copper contents, taking into consideration the slime which averages considerably higher than the sand, is about 0.75% copper with small values in gold and silver. The screen analysis gives the following approximate results:

All through 6 mesh.

On 8-mesh	5%
On 14-mesh	25%
On 28-mesh	28%
On 40-mesh	18%
On 65-mesh	6%
On 100-mesh	5%
Minus 100-mesh	13%

The best values are in the fine material, the copper contents of the material through 60 mesh being approximately 0.95% copper.

At present it is found that a mixture of light coal tar creosote combined with kerosene sludge acid has given the best results and this is what is being used at present. Good results have also been obtained with crude wood creosote and the addition of a small amount of pine oil and sulphuric acid. In general, however, the best results have been obtained in an alkaline solution rather than in an acid solution. Very complete tests indicate that an average extraction of 80 to 85% is entirely feasible. Almost all reagents are added to the Hardinge mills so as to get the benefit of the mixing action. A small part of the reagents are, however, added at the head of the standard cell.

Handling Joplin Slimes.—The treatment of Joplin slimes has been discussed by George Belchic and Glenn L. Allen,* who point out that these slimes constitute the material overflowing from the settling tanks and deposits in slime ponds. It may be divided into two classes: (1) slimes formed from a free milling ore, and (2) slimes formed from a "chatty ore," the latter being an ore in which the minerals are finely disseminated in the gangue rock and consequently requires finer crushing. The following screen analyses will suffice to show the difference in fineness of the material, as well as the assay, of slimes formed from chatty and free-milling ores:

* *Met. and Chem. Eng.*, Nov. 15, 1915.

Table I.—Slime formed from a chatty ore taken from a Joplin mill. This material assays 6.55% metallic zinc, and 99% of it passes through 150 mesh.

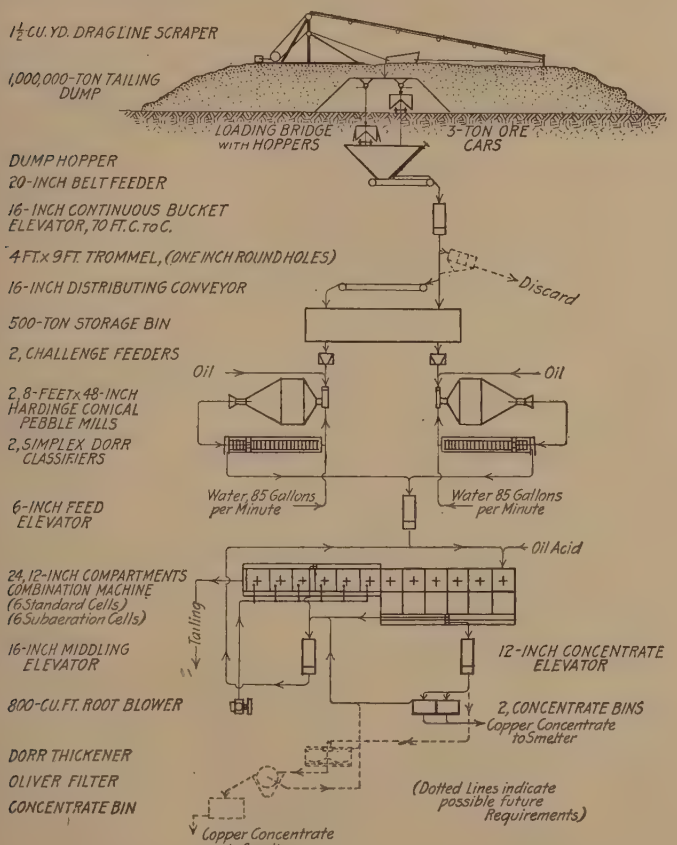


FIG. 45.—FLOW SHEET OF THE MILL OF THE UTAH LEASING CO., AT SALT LAKE CITY.

Table II.—Slime made from a free-milling ore, taken from a Galena, Kan., mill, and assaying 7.82% metallic zinc.

TABLE I

Opening, Inches	Mesh	Sample Weight, Grams	Per Cent	Per Cent Cumulative Weights	Per Cent Zinc
All pass through 0.0082	65	....	....	....	..
Retained on..... 0.0058	100	0.5	0.11	0.11	2.0
Retained on..... 0.0041	150	3.0	0.67	0.78	3.9
Retained on..... 0.0029	200	87.0	19.33	20.11	5.5
Through 0.0029	200	359.5	79.89	....	6.8
Total		450.0	100.00		

TABLE II

Opening, Inches	Mesh	Sample Weight, Grams	Per Cent.	Per Cent. Cumulative Weights	Per Cent. Zinc
All pass through 0.0110	50	....	....	....	..
Retained on..... 0.0091	60	9.0	1.84	1.84	3.41
Retained on..... 0.00675	80	5.0	1.04	2.92	2.06
Retained on..... 0.0055	100	12.0	2.48	5.40	2.77
Retained on..... 0.0036	150	21.0	4.35	9.75	3.59
Retained on..... 0.0020	200	268.0	55.48	65.23	7.86
Through..... 0.0020	200	168.0	34.81	....	10.30
Total		483.0	100.00		

Table III.—Gives the analyses of six samples of slime taken from various ponds in Galena, Kan., these samples covering the district geographically.

TABLE III

Sample	Per Cent Zinc	Per Cent Lead	Per Cent Iron	Per Cent Insoluble
1	3.77	0.69	4.58	85.87
2	7.82	1.09	4.46	70.75
3	5.57	0.37	10.78	78.81
4	3.69	0.41	3.08	88.87
5	7.43	0.45	7.81	81.23
6	4.20	0.26	4.18	81.27

The flotation tests were carried out with a laboratory experimental machine, and over a hundred tests were made, in order to establish the following factors:

1. Kind and amount of oil.
2. Effect of adding acid.

3. Effect of temperature.
4. Ratio of dilution of pulp.
5. Speed of agitation of propellers.
6. Time of agitation.

The oils used in the tests were pine oil, creosote oil, tar oil, crude petroleum, crude carbolic acid, cresylic acid, eucalyptus oil, rosin oil, oleic acid, rape-seed oil, and various combinations of the above. Tests were also made with mixtures of the above oils with carbon-bisulphide, benzine-sulphonic acid, kerosene, turpentine, etc. Summarizing the results of the numerous tests the following facts were established:

1. Good results may be obtained without the use of sulphuric acid, although a small quantity (0.5% of the weight of dry slime) in many instances brought the extraction somewhat higher without, however, increasing the zinc tenor of the froth-concentrate. With Kansas crude oil the addition of sulphuric acid is detrimental to flotation. Better results may be obtained if benzine-sulphonic acid be used instead of sulphuric acid with both crude petroleum and tar oils.

2. Comparatively high temperature (60° C.) gives better results with light pine oils and rape-seed oil, while room temperature (25° C.) is better suited for the heavy tar oils and crude petroleum.

3. Speed of agitation was found best between 1,200 and 1,500 r.p.m. Above 1,500 r.p.m. gangue material is often thrown over with the froth. Excessive speed of rotation produces, in many instances, air bubbles as large as 2 in., which carry readily both gangue and sulphide particles.

4. Pulp dilution varies with the fineness of the slimes. With very fine slimes a 7 : 1 dilution was found to give the best results. With coarser slimes a 3 : 1 dilution worked satisfactorily. With those slimes in which a large percentage of the particles is in colloidal form greater dilution is necessary to suspend the particles and allow the oil to surround the sulphide grains. Mechanical adhesion of sulphide and gangue particles in the froth are readily visible in slimes of this character.

5. Time of agitation in these tests ranged from five to ten minutes. This, however, is not so important since on a commercial scale the operation may be continuous.

6. The oils that gave the best results were the following:

Pine oil (specific gravity 0.937) gave a froth-concentrate assaying 53% metallic zinc, with an extraction of over 73%; 2.5 lb. of oil and 10 lb. of sulphuric acid were used per ton of dry slime. The slime feed assayed 5.17% metallic zinc with a trace of lead.

Rape-seed oil (specific gravity 0.85) gave a froth-concentrate assaying 48% metallic zinc, with an extraction a little over 55% when used in quantity of 10 lb. of oil per ton of dry slime, and without the use of acid. The slime feed assayed 5.17% metallic zinc with a trace of lead.

Benzine-sulphonic acid and tar oil (1:1 by weight) gave good results when used in the quantity of 8 to 10 lb. of the mixture to the ton of dry slime; a froth-concentrate assaying 56% metallic zinc with an extraction of over 50% was obtained. The slime feed assayed 3.69% metallic zinc and 0.41% metallic lead.

Carbon-bisulphide and rosin oil (1:1 by weight) gave a froth-concentrate assaying 40% metallic zinc, with an extraction of 50% when used in the quantity of 5 lb. of the mixture to the ton of dry slime. The feed assayed the same as the one above.

These preliminary results would indicate that the Joplin-Galena slimes, which at present are a waste product, might be treated on a commercial scale by flotation, and by this means the loss of zinc in milling in this district might be greatly reduced.

CHAPTER XIII

THE PRACTICE OF FLOTATION

The larger copper-mining companies have adopted flotation in many instances with a great measure of success. It has not been so long ago that the principal copper producers were placing a great deal of faith in leaching of the oxide orebodies and considering the roasting and leaching of many other of their low-grade sulphide deposits. All that has been changed, however, and the sulphide ores are now considered to be specifically within the range of flotation. One of the companies that has used the process with success is the Braden Copper Co., operating in the Chilean Andes of South America.

The Braden Mill.—The first Braden mill was built to handle 200 to 250 tons of ore a day and made use of crushers, rolls, Harz jigs, Huntington mills, Overstrom tables and buddles. Extraction was not high, but showed that the ore was amenable to concentration. During the construction of a new mill, the old mill was remodeled for experimental purposes, and in it flotation was tried out.

The ore, a shattered andesite, carrying approximately 75% of the copper content as chalcopyrite, the remainder being mainly bornite and some secondary chalcocite, being brought to the crushing plant from the mine over a 2-km. electric railroad, and after being weighed, was dumped into a coarse ore bin of 2,300 tons capacity. The mill, as now operated, is described by R. E. Douglass and B. T. Colley.* From the coarse-ore bin the ore, which is usually sufficiently fine to allow 25% of it to pass a 1-in. grizzly, is delivered by steel-belt apron feeders to the 30-in. conveyor belt in two sections serving two gyratories preceded by two inclined grizzlies. One 30-in. magnetic pulley at the discharge of the first section of the conveyor eliminates pieces of iron and steel received with the ore. The undersize of the grizzly goes

* "Metallurgical Operations at the Braden Copper Co.," *Eng. and Min. Journal*, Feb. 12, 1916.

direct to two 72 x 20-in. rolls and to two 6 x 30-in. trommels. The 72-in. rolls are run in closed circuits to the trommels, the undersize going direct as a pulp to the concentrating plant proper. A part of the grizzly undersize is at present being sent to a Marcy mill, the first of several that may be installed to increase the grinding capacity.

The discharge of the gyratory crushers, maintained at about a 3-in. maximum diameter, is taken by five 6 x 30-mm. trommels, the undersize going to the fine-ore bins of 3,000-ton capacity and the oversize to five 48-in. Symons crushers. The Symons-crusher product of approximately ⅜-in. maximum diameter is screened dry, the undersize going to a fine-ore bin. The oversize is dropped into four medium rolls, from which the discharge is taken by two 30-in. belt elevators to another set of 6 x 30-mm. screens at the top of the crushing plant. From there the oversize is continuously gravitated to the medium rolls and the two sets of 15 x 36-in. and two sets of 16 x 48-in. finishing rolls running in closed circuits, passing from there to the fine-ore bin.

That portion of the ore from the 72-in. rolls running in a wet circuit goes direct to the concentrating plant in a pulp, the dilution being kept as low as possible in order to avoid settling or derangement of the flotation plant from a too-dilute pulp. The pulp is concentrated on the upper tables, of which there are 48 in three sections of 16 each. All are fitted with a modified riffle that permits handling 150 to 200 tons per 24 hr. per table. The concentrate goes by launder direct to four pits at the foot of the mill, and the table-tail screening goes to Hardinge mills. The portion of the ore that was dry coarse-crushed and deposited in the fine-ore bins is sent by 3-in. inclined conveyors to three towers feeding that number of sections in the concentrator, each of 1,500-ton capacity. In each section this dry ore falls from the conveyor to eight screens, undersize going to the tables and oversize to two rolls in circuit, from which the undersize to two rolls in circuit, from which the undersize is also sent to the upper tables.

The object of this preliminary coarse concentration is to remove not only clean sulphides, but also the small amount of oxide and metallic copper, often adherent, which, with finer grinding, would be lost in subsequent operations both preceding and during flotation. The feed of these tables is not deslimed, because it is

not necessary. Desliming would also add more water to final pulp.

The Marcy mill, recently installed, ground an average of 456 tons per 24 hr.; the screen analysis of the feed and discharge being as follows:

MARCY MILL SCREEN ANALYSIS

Feed		Discharge	
On 38-mm.	4%	On 10-mesh	4%
On 25-mm.	20%	On 20-mesh	16%
On 16-mm.	24%	On 40-mesh	17%
On 8-mm.	20%	On 60-mesh	9%
On 10-mesh	25%	On 200-mesh	15%
Through 10-mesh	7%	Through 200-mesh	39%
	100%		100%

The tails of the upper Wilfleys flow directly to five drag classifiers feeding four 36-in. and one 48-in. Hardinge mills per section, a total of 15 mills in all. The overflow of these drags is manipulated to eliminate as much —60-mesh from the drag discharge (mill feed) as possible. The following is a typical performance of a 36-in. Hardinge mill equipped with a britannia lining:

WORK OF HARDINGE MILL

Weight of steel in lining, kg	6,900
Weight of cast-iron balls, max. 3½ in., dia., kg	3,500
Consumption of balls per ton ground, kg	0.75
Horsepower, full load	73.5
Tons per 24 hr	389
Water solid ratio of pulp discharged	0.52 to 1

SCREEN ANALYSIS

	Feed	Discharge
On 4-mm	5%	....
On 10-mesh	33%	....
On 20-mesh	37%	30%
On 40-mesh	14%	24%
On 60-mesh	4%	10%
On 80-mesh	1%	5%
On 100-mesh	1%	2%
On 150-mesh	1%	4%
On 200-mesh	1%	3%
Through 200-mesh	3%	22%
	100%	100%

On a bench below the upper row of Hardinge mills described is an auxiliary row of nine Hardinge mills, which take the discharge from the upper row through classifiers, as well as the occasional surplus or rushes from the upper Wilfleys that the first row may not be able to handle. The drag classifiers here are manipulated at the overflow in the same way as are the upper mills, in order to eliminate the — 60-mesh portion of the pulp as much as possible and to launder it directly to the flotation section. One section of this row and the corresponding section of the upper row are being tried out in closed circuit.

The discharge of the upper and auxiliary Hardinge mills is received by six large double-chain drag classifiers, two in each section, the overflow of which, manipulated to carry as little +60 solids as possible, goes to flotation and the thickened coarse discharge to 42 Wilfley tables, 14 to a section, all equipped with modified riffles.

The tails of these Wilfleys are laundered directly to 18 drag classifiers, feeding the same number of 30-in. Hardinge mills, there being 6 of each to a section. At present these are lined with silex, flint and local stone blocks; and local and Danish pebbles are used as grinders. Other types of liners and grinders are being experimented with. All these mills are run in closed circuit, with the object of producing the least possible +60-mesh solid in the finished pulp.

The following data are typical of the 30-in. Hardinge finishing mills:

WORK OF THE FINISHING MILLS

SCREEN ANALYSIS

	Feed	Discharge
On 20-mesh	24.3%	...
On 40-mesh	45.5%	12%
On 60-mesh	15.8%	11.2%
On 80-mesh	5.3%	8.8%
On 100-mesh	3.1%	9.2%
Through 100-mesh	6.0%	...
On 200-mesh	...	10.4%
Through 200-mesh	...	48.4%
	100%	100%

Ground per 24 hr., tons	86.4
Pebble load, kg	5,200
Horsepower	51.9
Water-solid ratio pulp	0.48 to 1

The finished pulp, or overflow from the drags of all sections, is received and sampled in one general distributing box.

The Flotation Treatment.—Until recently all this pulp was treated by flotation in six standard valve-type oil-flotation machines, with one more used for the retreatment of a free-running froth taken from the tail compartments of the six machines. Another plant was used for the retreatment of the slime overflow from the flotation concentrates pit. Four of the plants had 9 frothing compartments, two 11 frothing compartments, and two were of 12 frothing compartments. All were originally fitted with 5-in. circulating pipes. Agitator speed varied from 196 to 214 r.p.m.

Experimental work having demonstrated that increasing the diameter of the circulating pipes to 7 in. and coupling up two plants in tandem would greatly improve extraction and increase capacity, eight plants are being so arranged. The first of these double plants handled 1,460 tons per 24 hr. on the trial run. Experimental work having shown that no ill effects resulted from returning the free-running froth of the end compartments to the head of the machines for retreatment instead of to a separate plant, this practice is being continued.

The reagents used are Swedish or American pine-tar oil, fuel oil, sulphuric acid and a small amount of kerosene to thin the fuel oil. A portion of the pine-tar oil is pre-agitated in the lower Hardinge mills, the balance being added at the head of the flotation machine. The acid and fuel oil-kerosene mixture is added at the same point.

To handle the tails from the Minerals Separation standard plants 28 twin (one common partition) air cells have just been installed. The concentrates from the 28 primary air cells will be retreated in seven additional cells of the same type.

The flotation concentrate is settled in eight pits, four being used alternately. The settled Wilfley and coarser flotation concentrate is loaded directly, by a grab bucket, into side-dump cars for transportation to the acid or smelting plant.

Effect of Flotation on Smelting.—Shortly after the smelting plant began operations, the installation of the oil-flotation process in the mill imposed upon it an entirely new set of conditions. The concentrates produced as shown by this analysis (SiO_2 17.9, Al_2O_3 7.0, Fe 23.0, CaO 0.3, S 30.0, Cu 18.5) greatly improved

in grade of copper and of course of sulphur and iron, thus so reducing the silica and alumina that the necessity for limestone as flux disappeared. Also the fine crushing necessary in flotation methods gave a concentrate in which the alumina or colloidal material was so finely divided that it needed no clay as a binder, but which, on the other hand, was so wet that it could not be briquetted and was so fine that it was most difficult to filter or dry it.

These new conditions entirely changed the details of furnace operation. Where formerly the charge was only fairly fine but highly infusible, it was now all fines and excessively wet, but of much lower silica and alumina content and therefore easily fusible. The coke consumption, which under the first set of conditions had been 12%, now rose to 16% per ton of charge. This increase would not be expected in view of the betterment in fusibility of the concentrate. The reason was that each charge of concentrate went into the furnace in one huge blanket of mud that was absolutely impervious to blast penetration. Two such charges dropped on either side of the furnace successfully plugged all blast passages except the longitudinal center line of the furnace. Here the gases were obliged to escape through an extremely reduced aperture at a greatly increased velocity, carrying with them enormous quantities of heat which, under normal smelting conditions, is absorbed by the charge as the gases pass slowly upward.

During this period, when the flotation process was very new and before the arrival of the filter presses, concentrates of moisture content up to 40%, 50%, and 60% were smelted in this way. There were times when the concentrate would not stay on the belts and when the coke, which was always placed on the bottom of the charge car, would rise through the charge of concentrate and float on top of it.

The blanketing of the charge and the waste of heat through the narrowed aperture, caused by the water as moisture in the concentrate, was found to cost in increased coke a quantity equal to 50% of the moisture content; that is to say, every ton of water added under these conditions required 1,000 lb. of coke, or 50%, to evaporate it.

The 7-ft. ore column was found to be almost too high for such a dense charge, but on the other hand, any effort to reduce the

height allowed such large quantities of water so quickly to reach the tuyeres that chilling of the whole smelting zone was frequent, resulting in frozen spots or total furnace freeze-ups. The average tonnage per day on such a charge in a 300 x 44-in. furnace was: Concentrate, 135 tons; converter slag, 40; limestone, —; matte, 42; total, 217; coke, 35.

Practice at the Arizona Smelting Co.—The introduction of flotation, together with other changes in the milling scheme, at the copper concentrator of the Consolidated Arizona Smelting Co.,* increased the recovery of copper by more than 20% over the best saving previously made with jigs, tables, and vanners. The margin is sufficient to represent a difference between profit and loss, particularly when it is accompanied by a simplification of the process and reduction in cost for power and labor.

Milling ore from the company's Blue Bell and DeSoto mines is a siliceous sulphide containing pyrite and chalcopyrite in a gangue of quartz and schist. The average composition of the ore and mill products is shown in the table. In addition to mine ore, a variable quantity of mill tailing from former operations is also reground and concentrated. This material contains about 2% copper.

AVERAGE COMPOSITION, ORE AND MILL PRODUCTS

(Gold and silver in oz. per ton. Other constituents in per cent)

	Au	Ag	Cu	Insol	Fe	CaO	MgO	Al_2O_3	S
Milling ore	0.03	1.3	3.0	65.0	10.9	1.0	1.2	4.7	13.0
Table Conc.	0.09	2.3	7.0	10.0	35.0	..	..	..	...
Table Tailing Flotation Feed	0.025	1.0	2.1	...	5.8	..	..	..	...
Flotation Conc.	0.10	5.0	14.0	24.0	22.4	..	..	..	...
Gen. Mill Conc.	0.09	3.04	9.52	16.5	30.0	..	..	..	...
Mill Tailing Flotation Tailing	0.01	0.4	0.3	...	3.0	..	..	..	...

During September, 1915, the total quantity of ore milled was 7,173 tons. The average grade of mine ore was 2.7% copper, and of all material, including old tailing, 2.65%. The percentage recovery of valuable metals was 90.0% copper, 68% gold, and

* "Flotation at the Consolidated Arizona Smelting Co.," *Met. and Chem. Eng.*, Dec. 1, 1915.

72% silver. The gross amount of copper in concentrates was 345,000 lb., of which 240,000 lb, or nearly 70%, was recovered by flotation. The usual recovery by flotation will average about 75%

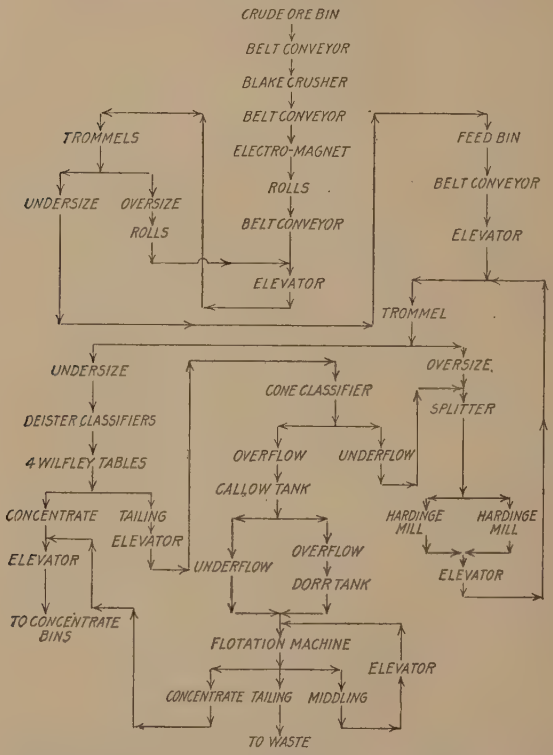


FIG. 46.—FLOW SHEET OF THE CONCENTRATOR OF THE CONSOLIDATED ARIZONA SMELTING CO.

of the total. The ratio of concentration in the entire mill was about 4, and in flotation between 7 and 8.

Effect of Changes in Milling Practice.—A diagram of the present flow sheet is given in the drawing. The ore is crushed dry in Blake crusher and rolls, screened in trommels and handled by belt conveyors and elevators in the usual manner. Water is first added at the boot of the main elevator indicated at the right

of the diagram. Hardinge mills are used for final grinding, and Wilfley tables and an eleven-cell Minerals Separation flotation machine recover the valuable metals.

The changes that have been made during the past year and a half, under the direction of G. M. Colvocoresses, general manager, and J. N. D. Gray, mill superintendent, have been directed toward simplifying and increasing the efficiency of the process, eliminating useless machines and reducing the cost of operation.

By taking out the jigs several beneficial results were obtained. The cost for power and labor was reduced and the general grade of concentrate increased. Also more favorable conditions for flotation were created, because the jigs used a large amount of water which made it difficult to maintain that uniformity in the flow of mill pulp which is essential to good work in flotation. The abandonment of vanners was a natural consequence of the adoption of flotation.

In its present simplified form the milling scheme differs radically from that used in an earlier day. Harz jigs, tables, and vanners were formerly used, but the recovery of copper under that system did not exceed 70%, in spite of the complicated treatment to which the ore was subjected. The pyrite, breaking coarser than the chalcopyrite, was easily concentrated, but the softer and more friable copper mineral entailed a heavy loss.

Similar ore conditions prevail to-day; but now the flotation process is effective at the very point in the treatment where tables and vanners proved inefficient. Wilfley tables are now used only for rough concentration, and flotation is relied upon for the major part of copper recovery. Pyrite concentrates easily on the tables, but floats less readily than chalcopyrite. The flotation product, on the other hand, not only contains twice the percentage of copper found in the table concentrate, but also represents 75% of the total recovery. Furthermore, about 60% of the flotation product is finer than 200-mesh, showing the need of an efficient method of fine concentration if a heavy loss is to be avoided.

The Consolidated Arizona Smelting Co. was one of the first in this country to adopt the Minerals Separation process of flotation. No acid is used and no heat employed. The flotation feed is table tailing thickened in a Dorr thickener. The dia-

phragm cone cuts out some coarse ore, which is reground, and the Callow tank removes sand from the feed to the Dorr thickener. Thickened pulps from the Callow tank and Dorr thickener are combined for flotation treatment.

Oil is added continuously to the inflowing pulp and the mixture then passes successively through the 11 cells of the machine. There is no retreatment or cleaning of concentrate, all froths being combined. The overflow of the last spitzkasten is regarded as a middling and is returned to the machine. The underflow from the last spitzkasten is the final tailing. A review of the essential mill data is shown in the accompanying table.

Ever since flotation has been in use it has been necessary to pay the closest attention to the chemical condition of the ore. A splendid recovery is made on clean, bright, fresh sulphides, but when the minerals become tarnished or suffer surface oxidation to a slight extent, or if the gangue becomes oxidized and forms decomposition products such as oxide of iron and carbonate of magnesia, the flotation froth is almost immediately "killed" and a serious drop in percentage recovery is noted. Extreme care is used, therefore, to send to the mill only clean sulphide ore. Oxidized material from the upper levels of the mine is smelted directly or, if it is high in silica, it is used for converter flux and fettling.

The Cost of Flotation.—The total cost of concentration, including coarse crushing and flotation royalty, is slightly over $1 per ton. In September it was $1.03. The cost of the flotation process, exclusive of royalty, has been $0.27 per ton over a period of six months. The oil cost has been gradually reduced to 2.8c. per lb.,* and the consumption averages a little less than one pound per ton of crude ore. The power consumed by the flotation machine for a period of 24 hr. is 32.7 kw. The record recovery in January made at this plant is but part of a comprehensive plan laid out by the management for placing the company's entire property—mines, concentrator, and smelter—on an economic and profitable basis.

Practice in the Globe-Miami District.—The Globe-Miami district of Arizona is now, and has been for some time, the scene of many important and interesting developments in flotation.

* Pounds per gallon: Stove oil, 7.12; wood creosote, 8.25; fuel oil, 7.48.

General Flotation Record of the Consolidated Arizona Smelting Co.'s Mill

Daily

1915	Feed Gradings						Density Ratio of H_2O to Dry Ore	Oil Consumption							Assay Values				Ratio of Conc.	Per Cent Recovery
	+ 35	+ 65	+ 100	+ 200	− 200	Total		Stove Oil	Cresol	Crude Turps	Tar Oil	Carbolic	Other Oils	Total	Lb. per ton Ore	Feed, Cu.	Tail, Cu.	Concentrate Cu.	Concentrate Insol.		
Jan.....	1.0	10.1	10.1	22.6	56.2	100	2.65	1844	195	1150	239	945	....	4373	0.661	2.47	0.935	15.82	31.2	10.3	66.2
Feb.....	1.3	10.7	11.1	20.2	56.7	100	2.40	2652	1643	1643	326	....	....	6264	1.080	2.59	0.32	16.66	25.9	7.3	89.4
March...	0.3	8.6	11.0	22.3	57.8	100	2.40	2601	1637	1629	325	....	....	6192	0.928	2.36	0.37	17.20	23.7	8.5	86.3
April....	0.0	8.2	12.4	28.3	51.1	100	2.70	2675	1678	1359	396	8	383	6499	1.158	2.12	0.28	14.28	23.0	7.8	88.5
May.....	0.0	3.8	9.9	30.2	56.1	100	2.60	2738	1571	1563	315	28	485	6700	0.995	2.22	0.29	13.20	22.4	6.8	88.9
June.....	0.1	5.2	11.8	30.9	52 0	100	2.40	2014	974	1451	311	478	287	5515	0.732	2.10	0.46	13.89	24.4	8.2	80.8
July.....	0.0	4.4	11.5	28.1	56.0	100	2.30	3644	529	538	107	200 Oil 1705	332	6855	0.948	2.09	0.26	13.90	26.8	7.5	89.0
August...	0.2	5.1	12.0	27.9	54.8	100	2.34	4074	442	443	91	1677	353	7080	1.034	2.11	0.27	13.99	26.8	7.4	88.8
Sept.....	1.3	6.1	10.3	29.6	52.7	100	2.10	4149	....	....	....	2074	357	6580	0.917	2.07	0.32	14.88	25.2	8.5	86.3

Weekly

	Gradings													Assay Values								
	Feed							Tailing						Concentrate			Feed			Tailing		
		+ 35	+ 65	+ 100	+ 200	− 200	Total	+ 35	+ 65	+ 100	+ 200	− 200	Total	Au	Ag	Cu	Au	Ag	Cu	Au	Ag	Cu
Jan.....	% solids.....	0.4	8.9	10.0	20.7	60.0	100	0.7	10.5	11.2	22.9	54.7	100	0.07	4.10	15.90	0.025	0.97	2.46	0.018	0.57	0.94
	Assay Value.	1.06	1.08	1.75	2.49	2.82	2.45	0.85	0.97	1.22	1.04	0.89	0.97									
	% Cu.....	0.2	4.0	7.1	21.0	67.7	100	0.2	4.0	7.1	21.0	67.7	100									
Feb.....	% solids.....	1.2	10.0	10.9	19.4	58.5	100	1.2	11.3	12.2	20.0	55.3	100	0.06	3.68	16.38	0.016	0.68	2.61	0.0075	0.27	0.32
	Assay Value.	0.84	1.05	1.88	2.95	2.91	2.60	0.73	0.81	0.59	0.27	0.17	0.32									
	% Cu.....	0.40	4.1	8.0	22.0	65.5	100	2.8	28.7	22.5	16.7	29.3	100									
March...	% solids.....	0.2	8.8	12.2	21.0	57.8	100	0.2	8.7	11.8	23.3	56.0	100	0.095	5.20	16.86	0.023	1.00	2.31	0.01	0.39	0.37
	Assay Value.	0.18	0.92	1.55	2.31	2.69	2 30	0.14	0.72	0.62	0.35	0.29	0.38									
	% Cu.....	0.1	3.5	8.2	20.8	67.4	100	0.3	17.3	20.0	21.4	41.0	100									
April....	% solids.....	0.0	6.2	12.6	27.2	54.0	100	0.0	6.7	13.5	28.5	51.3	100	0.106	4.63	13.82	0.022	0.93	2.13	0.01	0.34	0.29
	Assay Value.	0.0	0.79	1.24	1.97	2.56	2 14	0.0	0.58	0.49	0.23	0.21	0.28									
	% Cu.....	0.0	2.3	7.3	25.9	64.5	100	0.0	13.8	23.6	23.7	38.9	100									
May.....	% solids.....	0.0	5.3	10.0	29.7	55.0	100	0.0	7.8	12.8	27.5	51.9	100	0.11	4.35	13.28	0.025	0.95	2.25	0.011	0.37	0.31
	Assay Value.	0.0	0.87	1.29	1.92	2.68	2.23	0.0	0.71	0.42	0.23	0.23	0.31									
	% Cu.....	0.0	2.1	5.8	25.7	66.4	100	0.0	18.5	21.5	20.4	39.6	100									
June.....	% solids.....	0.2	7.5	12.0	29.3	51.0	100	0.0	7.0	12.7	29.5	50.8	100	0.11	4.22	13.88	0.030	0.92	2.16	0.017	0.45	0.48
	Assay Value.	0.30	0.91	1.17	1.82	2.08	2.11	0.0	0.63	0.67	0.43	0.48	0.50									
	% Cu.....	0.1	3.2	6.6	25.1	65.0	100	0.0	8.9	17.3	24.9	48.9	100									
July.....	% solids.....	0.0	5.2	12.0	30.0	52.8	100	0.0	5.61	2.02	9.6	52.8	100	0.11	4.88	14.00	0.024	0.88	2.04	0.011	0.34	0.28
	Assay Value.	0.0	0.75	0.94	1.77	2.65	2 08	0.0	0.56	0.40	0.26	0.25	0.30									
	% Cu.....	0.0	1.9	5.4	25.7	67.0	100	0.0	10.5	19.9	26.4	43.2	100									
August...	% solids.....	0.0	4.5	11.5	26.7	57.3	100	0.0	4.8	11.7	28.8	54.7	100	0.104	4.46	14.13	0.024	0.90	2.14	0.011	0.30	0.27
	Assay Value.	0.0	0.80	0.92	1.65	2.74	2.14	0.0	0.61	0.48	0.25	0.21	0.275									
	% Cu..... ...	0.0	1.7	5.1	20.1	73.1	100	0.0	10.4	20.5	26.5	42.6	100									
Sept.....	% solids.....	1.5	6.7	10.5	29.5	51.8	100	1.0	6.2	9.2	28.3	55.3	100	0.12	4.85	14.86	0.030	0.88	2.03	0.016	0.31	0.31
	Assay Value.	1.10	0.98	0.93	1.50	2.71	2.035	0.61	0.76	0.51	0.25	0.27	0.329									
	% Cu.....	1.0	3.3	4.8	22.0	68.9	100	2.9	14.4	14.6	22.1	46.0	100									

(*Facing page* 228)

combined with flotation oil in a collecting box beneath the classifiers. The sand runs into two hydraulic sizers, each of which has six pockets, and in each pocket there is a pair of Deister baffle-cone classifiers. Fine slime runs into a compartment at the end of the sizers and then to the collecting box under the drag classifiers. Material in this collecting box is elevated by two centrifugal pumps, each carrying half the stream, to a separate group of 12 Callow cells that make clean tailing and concentrate, which go to the same four cleaning cells that clean the concentrate from the first group.

The products from the two pairs of Deister cones making the coarser classification products go together to one Deister double-deck simplex sand table. Each of the other pairs of cones feeds one double-deck table, so that six sizes are made for table treatment; requiring eleven tables per section. The tables make clean concentrate, middling and tailing, but the middling now flows off into the tailing launder. A middling treatment will be undertaken later when the work of completing the mill will permit.

In sections 3 and 4 the flow differs in that the pulp from the Dorr classifiers goes to two sets of flotation machines of eight cells each, while the pumps and collecting boxes return to only one 8-cell machine; otherwise the flow is the same as in sections 1 and 2.

In sections 5, 6, and 7 no Callow machines are used, but Inspiration cells, devised at the property, are at work. The pulp from the Dorr classifiers goes to two machines of 16 cells each, the concentrates from which go to a similar set of two 6-cell machines and make a clean and finished concentrate, the tailing being returned by centrifugal pumps to the feed box of the first group of 16-cell machines. More flotation oil is added at the tailing compartment of the cleaner cells. The tailing from the 16-cell machines flow to a drag classifier, which delivers the coarse material to the Deister sizers, and treatment of the products from there on is the same as has already been outlined. The slime overflows from the drag classifier, together with the slime from the slime compartment of the hydraulic sizers, runs to waste from the collecting box, instead of being pumped back for further treatment, as is the case in sections 1, 2, 3 and 4.

The main tailing launder leads to three 60 x 10-ft. Dorr

thickeners, the overflow going to a large sump from which it is pumped back to the new water-storage tanks. The thickened underflow goes to the tailing. The present set of three thickeners is not of sufficient capacity to handle all the tailings, and seven more are to be added—three 100 x 10 ft., three 80 x 10 ft., and one 60 x 10 ft.

Handling the Flotation Concentrate.—All concentrate launders converge to a group of 60 x 10-ft. Dorr thickeners, the overflow from which goes to the same sump as the overflow from the tailing thickeners. The thickened underflow is raised by four bucket elevators to 12 x 12-ft. Oliver filters, the cake being scraped over a steam-heated plate and the dewatered concentrate dropping to a conveyor belt. It is then elevated to a steel concentrate-storage tank under which the concentrate cars can be started and the concentrate drawn into them for haulage to the smeltery.

The Inspiration flotation machine is built up of 16 compartments, each about 30 in. long by 42 in. wide, the partitions between cells being so arranged that the underflow of the first cell flows successively through all the others, in this respect somewhat resembling the flow through the Minerals Separation machines, but the flow is by gravity, or displacement, there being no agitators to lift the pulp. The cells of the 6-cell cleaner machine are smaller than in the 16-cell rougher. The air pipes are above the machines, and a branch from the air main runs vertically downward into each cell, instead of entering from below, as in the Callow cell.

The Globe-Miami district affords some interesting comparisons now in milling practice, in the procedure followed at the Miami, Inspiration, and Old Dominion mills. In the Old Dominion the ore differs from that treated in the Miami and Inspiration mills. A rougher, or bull jig, makes clean concentrate on a mixed feed, the concentrate being about ¼-in. size. The other jigs, together with a rougher or bull jig, recover the larger part of the concentrate produced. A Minerals Separation machine of 16 compartments treats slime, and some Callow cells have been installed for experiment. Flotation here produces a sort of end product—that is, only a small portion of the entire mill concentrate. Hardinge mills for regrinding and Symons disk crushers in the coarse-crushing department

are used, the only rolls being those recrushing the bull-jig tailing.

At the Miami mill, rolls are used both in the coarse-crushing department and in the mill proper, working on the feed from the mill ore bins and the coarse product from them going to the Hardinge mills. Callow flotation cells are used for the final treatment of slime, elevators raising the material, while the flotation oil is added at the launder running to the elevators. A Pachuca agitator was used for emulsifying the oil, but has been found unnecessary. The slime from one section is treated in a group of Callow cells, the concentrate from two sections being cleaned in a group of four similar cells.

At the old Dominion mill the 12 head cells of the Minerals Separation machine make a finished concentrate, the last four cells' overflow product being returned by the elevators to the head end of the machine.

At the Inspiration mill the flotation cells treat all the pulp and float some copper-sulphide grains even up to 40-mesh size, and the larger part of the concentrates are made by flotation. The tables recover a lower grade and work on material that has passed through the first, at least, of the flotation cells. The flow of pulp is direct, there being no regrinding once the material leaves the Dorr classifiers. There are no elevators in the mill except those lifting concentrates, and rolls are eliminated entirely. The arrangement of a mill treating 14,000 tons daily is remarkably compact. The plant probably covers less floor space per ton of capacity than any other mill.

The Bunker Hill & Sullivan Mill.—The operation of the Bunker Hill & Sullivan mill, at Kellogg, Ida., has been described by R. S. Handy.* It has concentration equipment with a maximum capacity of 585,000 tons per year. The total horsepower required is 1,500. Bronze ball crushers and disk crushers are used as preliminary breakers. The ratio of concentration is 7½ : 1. The total mill water used is 4,500 gal per min., and 45 men are required for operation.

The mill heads assay 9% lead and 3.5 oz. silver, while the tailings run 1.4% lead and 0.9 oz. silver. The percentage of extraction, therefore, is 84% lead and 78% silver. The accompanying flow sheet shows the scheme of operation at the mill. The

* *Eng. and Min. Journal*, July 1, 1916.

system is about as it has been in recent years, and since the adoption of flotation no radical changes have been made. There is no mineral-carrying pulp leaving the mill except that which flows through the automatic sampling devices.

The present arrangement of flotation equipment is shown in the flow sheet. The vanners are now run to produce a concentrate

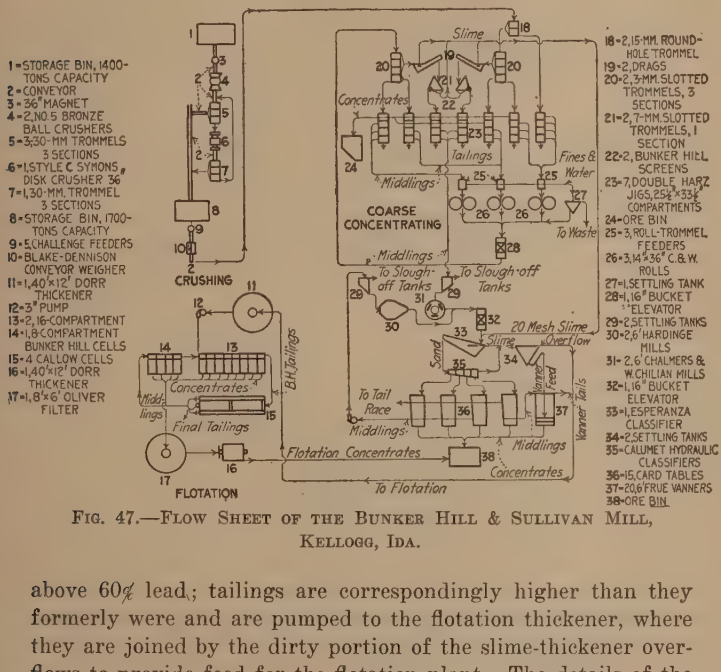


FIG. 47.—FLOW SHEET OF THE BUNKER HILL & SULLIVAN MILL, KELLOGG, IDA.

above 60% lead; tailings are correspondingly higher than they formerly were and are pumped to the flotation thickener, where they are joined by the dirty portion of the slime-thickener overflows to provide feed for the flotation plant. The details of the Bunker Hill flotation cell are shown in the accompanying drawing. The pumps are a specially made type, with white-iron liners, wearing plate and runner. In the stuffing-box is a cast-iron bushing of special design that allows the use of water packing to protect the shaft without unduly diluting the pulp in the cells. The water for this purpose comes from the concentrate thickener and contains considerable oil, which is an advantage. Compressed air is blown directly into the suction of these pumps under a constant head, so that this important regulation is easy

to maintain. The present pumps have been in constant service for seven months and show little signs of wear.

In the development of flotation the constant object has been to secure as high-grade products as possible for the same reason

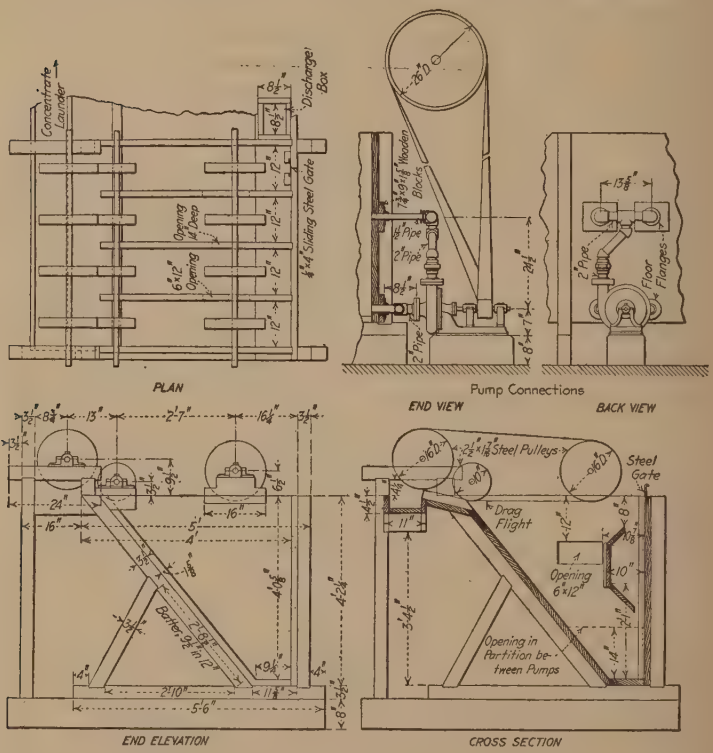


FIG. 48.—THE BUNKER HILL FLOTATION CELL.

that high-grade products are desired throughout the mill—namely, to obviate high freight and treatment charges. The sloping discharge for the froth of the Bunker Hill cell and the natural tendencies of the treatment itself permit the securing from these cells a froth assaying between 65 and 62% lead. The Callow roughing system consists of standard equipment with the exception that the pneumatic frame in the

bottom is made up of eight sections, and around each section a groove is cut so that the cloth cover may be secured by driving rope over the cloth into this groove in the same way that filter bottoms in cyanide tanks are secured.

The grade of froth from the Callow cells is about 30% lead, the object of these machines being to produce low-grade tailings, and the froth is cleaned up in a Bunker Hill machine. The flotation equipment in each section handles from 95 to 100 tons per day of material, about 95% of which passes 200-mesh. There are 16 pumps and 32 cells in the main Bunker Hill section and four pumps and eight cells in the cleaner section. Pine oil is used in one section of the mill and eucalyptus oil in the other. The latter makes a higher-grade froth than the former, and the consumption is a little over half that of pine oil. For keeping the dilution constant at 3 to 1 there is used a Troemner bullion scale, upon the sliding scale of which is laid out a curve giving the dilution due to a given weight of pulp.

CHAPTER XIV

THE PLACE OF FLOTATION IN METALLURGY

In view of the application of the flotation process to so many different kinds of metallurgy, its usefulness has apparently been shown to be exceedingly great. It is, up to this time, being applied to ores containing copper, zinc, lead, silver, molybdenum, and some other metals, in addition to the ores of gold and silver alone. In spite of this wide application, however, its definite position has not yet been taken. The ideas of metallurgists are continually on the change, and it is impossible at this time to forecast what the final field of the process will be. An authority who has been connected with the process since its first introduction into this country, and who has studied it carefully in many fields, predicts that its application will be just as wide as concentration in any other form. There is much reason to believe that this estimate is probably right.

Development at Anaconda.—In 1914 the technical press noted a plan for metallurgical improvement that had been inaugurated at Anaconda. At that time the contemplation of the Anaconda metallurgists was to go into copper leaching on a large scale, but their attention had just been drawn to the possible economic superiority of the flotation process, which might be substituted for mechanical concentration, and it was suggested that they stood ready to abandon the leaching feature of their programme in part or in whole, if that should appear desirable. Developments have shown that it was desirable, and it turned out that only the leaching unit then under construction was completed, it fitting well for a special purpose, while the main Washoe concentrator has been changed into a flotation plant, whose operation has already been noted in this volume.

The operation of this plant was commented upon editorially in the *Engineering and Mining Journal* of Nov. 13, 1915, which calls attention to the fact that in September, 1915, about 8,000 tons of ore daily were under treatment by the new process. By

applying the data derived from that month to the production figures of 1913, and computing on the basis of 14c. per lb. for copper, it was estimated that the saving would have been about $7,250,000. Putting the thing in a different way, the gain of valuable metals previously lost in tailing and slag would have been 50,000,000 lb. of copper, nearly 1,000,000 oz. of silver, and about 5,000 oz. of gold. This enormous saving is being effected at the cost of about $5,000,000 for the new plant. In other words, it is expected that the vast sum of money will be repaid in about eight months.

This saving has not been altogether due to flotation, but it is largely there. Formerly the tailing wasted at the mill assayed about 0.62% copper, while now it is only about 0.1%, and there is reasonable expectation that even that small figure will be bettered. The Anaconda ore fed into the mill contains 60 lb. of copper per ton, of which only 1¾ lb. now goes away in the tailing. The recovery is therefore about 97¾%. Other great items of the saving are the improvement of the reverberatory smelting process by the introduction of coal-dust firing; the abandonment of briquetting and blast-furnace smelting in favor of the new reverberatory process, and the saving in freight resulting from the direction of all the concentrating ore to Anaconda, instead of sending some of it to Great Falls. Some saving and profit has been through the operation of the leaching plant.

Another expression of opinion upon the subject is given by W. R. Ingalls in an article on "Electrolytic Zinc," appearing in the *Engineering and Mining Journal* of March 4, 1916. Mr. Ingalls says:

"Another new and uncertain factor is the bearing of flotation process of ore concentration upon the metallurgy of zinc. I think this had a good deal to do with the institution of the Anaconda work. About all metallurgical work is a sequence of steps of concentration and refining, treating the bulk of the ore by a cheap but wasteful process, and delivering the concentrated product to a more costly but less wasteful process. Now, most experimenters in the hydrometallurgy and electrometallurgy of zinc heretofore have contemplated the application of a costly process to run of mine ore. The flotation process has enabled ore to be concentrated at relatively small cost with but slight loss. Let it be observed, therefore, that Mr. Laist is applying his costly

process not to run-of-mine ore, but to flotation concentrate in which about 90% of the zinc is contained in about one-fourth of the original weight. This is the new and important feature of recent zinc electrolytic work.

We must let our thoughts run a little farther ahead. The treatment of flotation concentrate is one of the present troubles of the zinc smelter, owing to its excessive fineness, which produces difficulties that it would take too long to describe. Yet the proportion of this class of ore that the zinc smelter is getting is still relatively small. The supply of it is, however, bound to increase, and when it becomes large the troubles of the zinc smelter will really begin."

The mechanical disposal of flotation concentrates has been discussed by R. J. Anderson.*

The Handling of Concentrates.—Flotation concentrate, *i.e.* the froth entangling the valuable sulphides (and gangue in subordinate amount) plus water, is an unsmeltable product as such. The first step in the disposal operations requires a breaking of the froth, particularly if it be a mechanical froth, such as is produced by the Minerals Separation, Hebbard-Harvey, Janney, or similar mechanically agitated machines. The pneumatic froth of Callow or Flynn-Towne is ephemeral and breaks of itself when removed from the influence of the injected air (although, of course, its stability is influenced by the kind of oil used), and is, therefore, more easily handled. The mechanical froth, however, is thick and more or less permanent, and its disposal has presented serious difficulties.

A common practice for froth breaking, which is quite effective, simply calls for the spraying of water on the froth as it flows in its launder. In a number of instances bucket elevators have proved quite efficacious; the splashing and striking of the buckets causes the froth to break up. At the Herculaneum plant of the St. Joseph Lead Co. there have been installed pug-mills for this purpose. In addition, these mills insure a steady stream of concentrate feed to the mixing belt whereby the flotation product is mixed uniformly with the usual feed for the Dwight and Lloyd sintering machines. The method of running the concentrate over tables of the Wilfley or Card type has been tried and is successful in breaking up the froth. Froth may also be

* *Met. and Chem. Eng.*, April 1, 1916.

effectively broken by the addition of reagents such as acid or lime, or even by adding more oil. In regard to this latter, if an excess of oil is added to a successfully operating flotation unit the froth may be practically "killed." A filter of the pressure type will break up the froth in the dewatering operation.

Dewatering the Concentrate.—All flotation processes produce a wet, sloppy, frothy concentrate which is extremely difficult to handle and ship unless dewatered. The skillful and economical disposal of flotation concentrate preparatory to shipment and smelting is, therefore, an important problem. In discussing dewatering practice, certain machines have found their way into the mills and certain methods have been adopted which probably embody the tendencies toward a future standard practice. Some of the apparatus used for dewatering includes settling bins, filters—pressure or vacuum, drag-classifiers, screw-classifiers and thickeners.

The practice of settling the froth in bins, while a common one, does not reduce the moisture sufficiently low for shipment by rail unless for short distances. The mill of the Utah Leasing Co. at Newhouse, Utah, has large bins of 200-ton capacity for settling the concentrates. Practically all of the larger plants have come to the use of filters either of the pressure or vacuum type, or both.

The functional utility of the filter lies in its ability to reduce the moisture content of the material treated to practically any desired percentage. Pressure filters of the Kelly type can take the flotation froth direct and perform the function of froth breaking and dewatering in the same operation. The pressure filter is more bothersome to operate, because it is intermittent in action and requires constant attendance. Although the pressure filter can reduce the moisture content to as low as 6%, the vacuum type finds more favor. This type of filter is not well adapted to the immediate dewatering of froth concentrates because such product will not cake well on account of its high percentage of moisture—60 to 70% and occasionally considerably more. The pulp feed for vacuum filters should have a ratio of 1 to 1. If the froth be first broken and then dewatered in a Dorr tank, the vacuum filter can be used, and it is preferable to the pressure type by reason of its continuous operation and low

operating cost. The vacuum filter in practice can make concentrates of any moisture content to as low as 8 to 10%. Where concentrates are to be briquetted, such a low percentage of moisture is not necessary, but should be as high as 15% or more.

An example cited recently in the current technical literature, which gives a method of dewatering flotation concentrates, is the practice at the Inspiration mill in Arizona. Here the concentrates from the flotation processes and from the tables converge to a drag-classifier; the coarse product from this machine is sent to an Oliver filter and the fine product to a V-shaped settling tank, where it is thickened. The thickened and settled fine from the tank then goes to the filter. The filter cake from the Oliver machine is trammed to a bin and thence loaded into bottom-discharge railroad cars for shipment to the smelter. At the Miami mill in Arizona, the flotation concentrate is thickened in Dorr tanks and the thickened product then conveyed by bucket elevators to a group of 12-ft. x 12-ft. Oliver filters. The caked concentrate is scraped off over a steam-heated plate and then removed to a steel storage tank preparatory to shipment to the smelter.

A type of machine brought out in recent years by one of the Western companies which is applicable to the dewatering flotation concentrates is the so-called Ovoca classifier. This is a classifier of the screw type. The froth is broken down effectively, giving a continuous clear overflow solution at the weir and a continuous discharge of dewatered concentrate—moisture 15 to 25%. A screw dewaterer is in operation at the Oneida Stag mill at Idaho Springs, Colo. At this place the flotation concentrate plus the table concentrate is passed through a screw dewaterer and the two are thus mixed and dewatered in one joint operation. The dewatering machine removes from 60 to 70% of the slimes with the coarser table product, and the overflow removes the balance of the slime. This latter goes to settling boxes and is there settled and thickened.

The practice of washing flotation concentrate is a development as yet new in American practice. The leading consideration in washing is the removal of part of the insoluble matter whose presence in the final concentrate detracts from its grade. Washing is employed at a New South Wales mill in Australia.

Here the flotation product is led into settling bins and washed by means of spray water playing on it as it enters. The effect of this is to disintegrate the froth so that the sulphides sink to the bottom and at the same time part of the floated gangue is carried over the lip by the moving stream of water.

Drying the Concentrate.—Drying is an important consideration, particularly when the concentrate has to be shipped long distances. Every pound of water in the shipped product has to be paid for as freight, hence should be as low as possible. The advantages of dewatering and drying lie in reducing the water content, and therefore the freight charges; and preventing loss of slimy concentrate due to leaking tanks and cars. It also avoids the trouble due to freezing in cold weather.

At Engels, Calif., the flotation concentrate is settled and thickened outside the mill. The thickened concentrate is then filtered in a machine of the Oliver type, making a cake containing 10 to 12% moisture. To reduce the moisture to 5 or 6%, because of the long shipping distance, an unused drag classifier has been remodeled so that heat can be applied beneath it, and the material dried in it. The dried concentrate is sacked, hauled to the railroad, and the sacks then emptied into railroad cars for shipment to the smelting plant.

Flotation and Cyanidation.—In discussing the comparative values and fields for flotation and cyanidation, one of the important questions that arise is how the flotations concentrate, when made, is to be treated, particularly in isolated plants. It may be desirable in many cases to treat this material on the ground where it is produced, and cyanidation has been proposed, and sometimes used, as a process for doing this in the treatment of precious-metal ores.

It is evident that trouble may possibly occur through the oil contained in flotation concentrates, that may be detrimental to cyanide treatment, possibly acting as a cyanicide. Some operators have made actual tests, and in fact are treating flotation concentrates from precious-metal ores without any difficulty, and one operator has announced that no difficulty was found in such a system of operation. In other cases, however, great difficulty has been found, the consumption of cyanide proving altogether abnormal. The difficulty then, apparently does exist sometimes, but not always. In connection with this

subject, Professor Clevenger, of Leland Stanford University,* points out:

"The remedies suggested have been saponification of the oil film by preliminary treatment with a caustic alkali; washing with a light mineral oil, such as gasoline, which is presumed to act as a solvent for the oil film; and various other expedients which have been tried more or less at random. The efficacy of these remedies in cases where real difficulty exists has not been clearly demonstrated. Where fuel is cheap and roasting can be done economically, a thorough oxidizing roast will, with but very few exceptions, solve the problem in the case of concentrates containing gold with little or no silver; but as I have elsewhere pointed out on a number of occasions, silver minerals are rendered refractory to cyanidation by an oxidizing roast. The chloridizing roast in such cases may be at times effective, but is not generally looked upon with favor by metallurgists on account of the possibility of loss of the precious metals. It is here sometimes suggested that the oil may be carbonized during roasting and thereby cause premature precipitation. This objection is not well founded, since with proper roasting it would be entirely consumed.

It seems to be the opinion among thoughtful metallurgists who have not been completely carried away by the wave of enthusiasm which has struck the world for flotation, that flotation will not to any considerable extent displace the cyanide process in the treatment of gold and silver ores, but, as previously pointed out, it will in some cases, perhaps a good many, prove more economical, and it will in many other cases prove a valuable accessory treatment to cyanidation. The reason that flotation will not displace the cyanide process is that most companies prefer to produce bullion. Furthermore, many gold and silver mines are situated far from smelting centers, which entails high freight rates and renders the shipment of concentrate out of the question. Some possibility, however, exists which tends to render such a prediction uncertain, and that is the possibility of obtaining an extremely high-grade concentrate such as could be directly melted with simple furnace equipment in much the same manner as cyanide precipitate. If we can conceive of this ever being accomplished, and it is not im-

* *Met. and Chem. Eng.*, June 15, 1916.

possible, then cyanidation will certainly have a most formidable rival in flotation."

In talking on the same subject, Ernest A. Hersam, in *Metallurgical and Chemical Engineering,* June 15, 1916, points out that: "The greater number of oils allowed to remain in flotation concentrates are not chemically without action upon cyanide solution. Most oils have chemical qualities which also interfere by the absorption of oxygen. The animal and vegetable oils are generally oxygen consuming. Combining with the oxygen at a critical time and place, when gold combines with the cyanide and when oxygen is needed, the extraction fails. Reduction and side reactions result in an attack upon the cyanide solvent. Particular interference is liable in the presence of the sulphide minerals soluble in alkali. Compounds as well, between mineral bases and oily acids, produce physical effects that retard the dissolving action."

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